IEEE
Canadian Review
La revue canadienne de l'IEEE

Group Think

Cooperative Control of Multiple Unmanned Aerial Vehicles

- **Information And Communication Technology Usage Behavior**
- **Approches heuristique pour l'àffection de cellules aux commutateurs dans les réseaux mobiles**
- **CRM Package Implementation in a Multi-National Bank**
- **HSDPA: An Overview**
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(ii) Canadian members of the profession and community who are non-members of IEEE;
(iii) The associated Canadian academic (i.e. universities, colleges, secondary schools), government and business communities.

To ensure that the *IEEE Canadian Review* has the desired breadth and depth, editors are responsible for screening articles submitted according to the following general themes:

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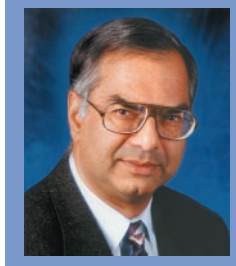
Quelques mots du rédacteur en chef

Vijay K. Sood, Hydro-Québec

C e numéro de la revue canadienne débute avec le rapport d'introdution de Bill Kennedy (à la page 5), en tant que nouveau directeur de la région 7. Je tiens à remercier Mo El-Hawary pour ses contributions à titre de directeur de la région au cours des deux dernières années.

Ce numéro de la revue canadienne innove, encore une fois, avec deux articles en français. Je suis très satisfait de voir nos efforts dans cette direction être récompensés. Je vois déjà une tendance très saine, et nous aurons un autre article en français dans l'édition estivale. Soit dit en passant, le prochain numéro est déjà complet! Avoir des articles en banque est très positif et rend ma tâche d'autant plus facile. Je pourrais facilement commencer le prochain numéro et l'expédier avant sa date prévue de publication, sauf que notre trésorier ne serait peut-être pas très content.

Un des problèmes qui demande encore du travail a trait aux revenus de publicité et de commandite. C'est probablement la prochaine barrière à franchir avant de devenir un journal d'une certaine envergure. Pour que ça se réalise, vous, les membres, pouvez aider. Sil vous plaît, informez vos collègues et collaborateurs en entreprises qu'une publicité dans la revue canadienne atteint près de 15 000 lecteurs, lecteurs avec un haut niveau de connaisances technologiques et scientifiques et très influents dans ce qu'ils consomment. Pour ceux d'entre vous qui sont dans les divisions de marketing de corporations, vous pouvez certainement transmettre ce message.

Finalement, la conférence CCGEI 2004 se déroulera à Niagara Falls au mois de mai (voir pages 31 et 32). On m'a dit qu'il y a eu un nombre record d'inscriptions. J'ai hâte d'y assister.

Opinion

I am 55+ years old and some years ago, following my generation's dream of retiring at 55, I decided to take the envied plunge. Things were getting tiring at work, and my employment was becoming a real pain in the you-know-what. So I decided that travel, tending after the garden, and wining-and-dining would occupy happily the rest of my remaining life. These would be the fun activities that I missed so much and, if the good spouse would permit, I could even go to a Bridge session once in a while.

Things have not turned out as expected. First, the retirement package that was invested heavily in the stock market plunged thanks to the telcoms bust. Second, the youngsters who had departed to make their fortunes elsewhere (far far away), discovered that they could not cope with the fast life and decided to return home. And third, the travel became too rich for the pocket and the wining-and-dining became too rich for the stomach.

So, as it turns out, I need to get back. For those of you who wrote me off, look carefully, ...very carefully behind you. For those of you who missed me, ...smile, 'cause we shall have those "Happy Days are here again" sing-alongs soon. And for those of you who don't care, ...fret not, 'cause you are the chosen ones.

So, in the words of the famous governor: I'll be back. Watch me.

Baby Boomer

Cover picture / *Photo de couverture*

Teams of unmanned aerial vehicles (UAVs), such as these Boeing UCAV X-45s, are likely to be deployed much more often in the future by both the military and civilian airspace communities. Cooperative control systems are needed to reduce computing costs and to make the team more robust. For electrical and hardware/software engineers, the challenge is to keep the communications and computing demands achievable within the limits of communications bandwidth and computing power that is feasible on such vehicles.

A few words from the Managing Editor

T his issue of the CR46 commences with the introductory report from Bill Kennedy (on page 5), as the new Director of Region 7. Mo El-Hawary now moves on to being past Director of the Region and I wish to thank him for his contributions of the past two years.

This issue of the CR is breaking new ground, once again, as we have two articles submitted in French. I am personally very satisfied to see that our efforts in this direction have finally borne fruit. I already see a very healthy trend, and we will have another French article in the following summer edition CR47. By the way, the next issue is already full! This trend for having articles in the bank, so to speak, is very positive and makes my task that much easier. I could easily start the next issue and ship it out ahead of schedule, except that our Treasurer may not be too happy about that.

One of the problems still needing some work has been with the advertising and sponsorship revenues. This can be the next target hurdle to overcome before we can truly become a journal of some calibre. For this to happen, you the membership can help. Please inform your contacts in the commercial environment that advertising in the CR reaches some 15,000 potential readers who are very knowledgeable and can be quite influential in what they consume. Those of you who are in the marketing divisions of corporations can certainly take this message forward.

Finally, the CCECE 2004 conference is in Niagara Falls in May (see pages 31-32). I am told that a new registration record has been set. I look forward to being there.

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Canadian Newslog / Coupures de presse Canadienne

Newslog Editor

Rédacteur des Coupures de presse

Alexandre Abecassis is a patent agent trainee in Montreal at Ogilvy Renault, Lawyers and Patent and Trade-mark Agents.

Alexandre Abecassis travaille à Montréal chez Ogilvy Renault, Avocats et agents de brevets et de marques de commerce, comme agent de brevets en formation.

Send any news clippings you would like to contribute via e-mail to alexandre.abecassis@ieee.org

Veuillez faire parvenir les coupures de presse proposées par e-mail à alexandre.abecassis@ieee.org

TORONTO, ON, Jan. 8 2004. Sangoma Technologies Corporation, which is a leading provider of connectivity hardware and software products for Wide Area Networks and Internet infrastructure, has provided George Brown College of Toronto with one of its WAN product in order to enhance the school's networking curriculum offerings.

MONTREAL, QC, Jan. 23, 2004. Isacsoft and the Ecole nationale de Police have entered into a partnership agreement. In fact, Isacsoft will provide development tools such as a training management platform, while the Ecole nationale de police du Québec will offer its expertise in matters regarding patrolling, traffic safety, use of force and investigation.

SAULT STE. MARIE, ON, Feb. 4, 2004. Amperion, Inc., which provides broadband over power line technology, and PUC Telecom, provider of telecommunications services have announced that a broad-band over power line solution has been deployed in Sault Ste. Marie, Ontario.

TORONTO, ON, Jan. 27, 2004. Tri-Vision Technologies, has announced that it has entered into a licensing agreement with USA Video Interactive Corporation to market and distribute USVO technologies. One of the USVO technologies is related to video content protection using water-marking. Watermarking is used to protect a content by inserting information which is not detectable by a user.

CALGARY, Jan. 14, 2004. M-Tech Information Technology has announced that Cessna Aircraft Company has purchased one of its product which is a pass word management solution. Such solution is used to reduce help desk support and administration costs, to further increase user productivity and enhance corporate security. Cessna Aircraft was looking for a management solution to reduce the over 44,000 password reset calls per year.

MONTREAL, Jan. 6, 2004. NSTEIN Technologies, which provides software solutions for managing and retrieving unstructured information, has announced that it has signed an agreement with Health Canada to spear-head a new Global Public Health Intelligence Network platform for monitoring potential public health risks and threats around the world. The network is an initiative developed by Health Canada in collaboration with the World Health Organization to monitor, aggregate and disseminate health information to the international public health community in order to provide an early warning of potential public health risks or threats.

EDMONTON, Dec. 2, 2003. Intuit Canada has licensed CodeBaby's 3D virtual agent technology. Under the agree-ment Intuit will introduce its customers to "Laura", a customized, interactive, CodeBaby virtual agent who will assist the users in completing their tax returns online. Laura will deliver, *inter alia*, tax tips, advice, etc.

OTTAWA, ON, Nov. 19, 2003. Raytheon Canada has been awarded a Preferred Supplier Award by NAV CANADA. Raytheon Canada is being recognized for its achievements on the Canadian Automated Air Traffic System (CAATS) and Northern Radar Programs.

VANCOUVER, BC, Nov. 18, 2003. Partners for the Advancement of Collaborative Engineering Education have announced a contribution with a commercial value of approximately $240 million to the University of British Columbia (UBC) today. This contribution, the largest in UBC's history, consists of computer-aided design, manufacturing, and engineering software, hardware, and training. The PACE is a corporate alliance between various large corporations.

LONGUEUIL, QC, Feb. 26, 2004. D-BOX was presented with the "2004 Titans Award" for its motion simulator system, which was recognized as the year's best Canadian technological innovation during the "Celebration of Science" gala event, held by the Foundation of the Montréal Science Centre. The motion simulator system adds a new dimension, movement, to home theatre viewing and video games.

TORONTO, ON, Feb. 23, 2004. The Canadian Air Transport Security Authority has chosen ACME~Future Security Controls to develop a comprehensive solution for the operational trials of CATSA's restricted area identification card project to improve security at Canadian airports. Biometric technologies will be used in order to create a secure credential card for individuals accessing restricted areas of airports. A central database will further be used to verify the validity of any card issued in Canada.

OTTAWA, ON, Jan. 15, 2004. The Canadian Department of Justice has signed with CGI Group a five-year IT outsourcing contract valued at CDN$14.5 million. CGI will provide the Department employees with a national service desk along with onsite support services, systems and network management and equipment maintenance in the National Capital Region.
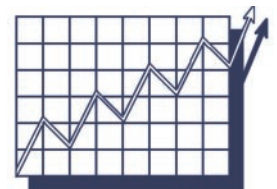
The New Year brings hopes and aspirations for something new. IEEE Canada also has something new to offer - a changing of the guard. Mo el-Hawary has completed his two-year stewardship of IEEE Canada and to use a railway expression, a change of crew has occurred and a new engineer is driving the train. I want to use this column to introduce some of my aspirations for Region 7 and I will use this column throughout my two-year stewardship to update you on the changes in Region 7.

The governance and finances of Region 7 haven't been examined in a number of years and it's time we reviewed how we govern and finance ourselves. To that end, I've appointed a group of three distinguished Region 7 members to review the governance and finances. Wally Read will head the review committee and Ray Findlay and Vijay Bhargava will ably assist him. I've asked the committee to complete their review before the Region 7 Spring Meeting in Niagara Falls in May of this year. Ideally, the Region Committee will deal with the report and hopefully the Region Committee will accept the changes recommended by the Review Committee.

Region 7 hasn't conducted any formal training for incoming Section Executive in a long time. Starting with the Spring Meeting, the Central Canada Council will conduct a one-day training session for incoming Section Executive. Region 7 will assist CCC Sections sending one member to the training session by paying half the travel and accommodation costs. Additional training sessions with the same cost sharing structure are planned for the other two councils and they will take place at the Fall Meeting in Calgary for the WCC and at a meeting to be held in Moncton in September for the ECC concurrent with the annual SAC meeting. The Region ExCom will also hold a face-to-face meeting concurrent with the ECC training session and SAC meeting. We need to provide some networking opportunities for our student members.

At the Spring Meeting in Niagara Falls, Region 7 will host a Membership Development Retreat. This is the first time the Membership Development Retreat has been held outside of Piscataway and the retreat will be directed specifically at Section MDC Chairs. IEEE Staff from Piscataway along with RAB volunteers will participate in the retreat. We have also invited MDC Chairs from Regions 1 and 2 to attend the Niagara Falls meeting. To encourage maximum participation at the retreat, Region 7 will pay half the travel and accommodation costs of Section MDC Chairs. Personally, I am excited about this retreat. My hope is that the Section MDC Chairs will come away from this retreat energized and that throughout Region 7 this will translate into membership growth.

Finally, please feel free to write me, I can be contacted at w.kennedy@ieee.org. By the way, IEEE has incorporated a spam filter for IEEE e-mail that I have invoked and it works! To get yours, you need an IEEE e-mail alias and an IEEE Web Account. Then go to https://uce.ieee.org and follow the instructions.

Bill Kennedy,
IEEE Region 7 - Director/Président,
Calgary, AB
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La nouvelle année nous apporte l'espoir et l'espérance d'un nouveau départ. IEEE Canada vous apporte aussi du nouveau - un changement de la garde. Mo El-Hawary a complété son mandat à la tête de IEEE Canada, et, pour utiliser une expression des chemin de fer, un nouveau conducteur est à bord. Je veux profiter de cet article pour introduire certains de mes ambitions pour la Région 7 et, tout au long des deux prochaines années de mon mandat, j'utiliserai cette rubrique pour vous informer des changement dans la Région 7.

Les principes de direction et finances de la Région 7 n'ont pas été revus depuis de nombreuses années. Il est temps de revoir nos principes de gouvernance et de financement. À cet effet, j'ai assigné un Comité de Revue composé de trois membres distingués de la Région 7 à cette tâche. Wally Read sera en charge du comité de révision aidé de Ray Findlay et Vijay Bhargava. J'ai demandé au comité de compléter leur revue avant la réunion du printemps, prévue pour le mois de mai à Niagara Falls. Idéalement, le Comité Régional passera en revue le rapport présenté et, je l'espère, celui-ci acceptera les changements recommandés par le Comité de Revue.

La Région 7 n'a pas eu depuis longtemps de cours de formation pour les nouveaux cadres de Section. Débutant à la réunion du printemps, le Conseil Central du Canada (CCC) présentera un cours d'une journée pour les nouveaux cadres de Section. La Région 7 aidera financièrement les Sections du CCC en payant la moitié des frais de déplacements d'un membre enrôlé dans ce cours de formation. Des cours de formations supplémentaires, avec aide financière équivalente, sont prévus pour la réunion automnale à Calgary pour le WCC (Western Canada Council) et la réunion en septembre à Moncton pour le ECC (Eastern Canada Council). Cette réunion a lieu conjointement avec la réunion annuelle du SAC. Le Région ExCom aura aussi une réunion en personne au même moment. Ceci donnera aux membres étudiants l'occasion d'établir de nouveaux contacts professionnels.

À la réunion du printemps à Niagara Falls, la Région 7 offrira une retraite pour l'augmentation de l'enrôlement des membres de la société (Membership Development Retreat). Ce sera la première fois que cette retraite à lieu a extérieure de Piscataway, et elle sera conçu spécifiquement pour les directeurs à l'accroissement du nombre de membres de chaque Section. Le personnel de IEEE de Piscataway ainsi que des volontaires de RAB participeront à cette retraite. Nous avons aussi invité les directeurs à l'augmentation de l'enrôlement des membres des Sections de la Région 1 et 2 à la réunion de Niagara Falls. Pour encourager une plus grande participation à cette retraite, la Région 7 paiera la moitié des frais de déplacement des directeurs à l'augmentation de l'enrôlement des membres des Sections. Je suis personnellement très excité à l'idée de participer à cette retraite. J'espère que les directeurs à l'augmentation de l'enrôlement des membres des Sections sortiront de cette retraite revigorés et que dans l'ensemble de la Région 7, nous verrons une augmentation des membres.

N'hésitez pas à m'écrire. Vous pouvez me rejoindre par courriel à w.kennedy@ieee.org.

Une dernière note: IEEE a introduit un filtre pour réduire la quantité de spam. Pour l'utiliser, vous avez besoin d'une adresse de courriel avec IEEE et un compte Internet avec IEEE. Avec ceci en main, connectez-vous à https://uce.ieee.org et suivez les instructions.

Happy Easter   Joyeuses Pâques

Information And Communication Technology Usage Behavior: The Case Of Salespeople In A Canadian Telecommunication Firm

1.0 Introduction

Salespeople in high-technology-based industries, such as the telecommunications industry, are undergoing profound, irreversible changes. They work in organizations characterized by a capacity to succeed amidst market and technological uncertainties and competitive volatility [1]. Democratization of the Internet 20 years ago has changed and shaped the way business is conducted by offering different sales channels. Customers are better informed and more demanding and have timely access to products and services. As streams of ICT continue to glut the market, organizations are acquiring these new technologies in order to collect, manage and distribute data about customers and thus serve them better. The race to streamline organizations is being run flat out, and firms are adopting technology to automate every organizational function. When a sales department adopts many different ICT to enhance its effectiveness and efficiency, the process is often referred to as sales force automation (SFA). SFA tools vary in complexity and the degree to which they need to be integrated into organizational infrastructure. Market trends indicate a move toward more automation from SFA to CRM softwares, then to Internet-based CRM (eCRM), followed by wireless applications (mCRM), sales and marketing automation (SMA), then integrated marketing (IM), enterprise resource planning (ERP) and, lastly, near complete automatization with partner relationship management (PRM) [2]. In such a context, complexity can increase exponentially and consequences for people and organizations become far reaching as automatization progresses.

To understand the impact of automatization on the sales force, this paper takes the salesperson's perspective and examines which ICT are being used in an interrelated manner. We investigate usage patterns in a high-technology-based sales force to determine whether it is oriented mostly toward emerging or mature technologies, or perhaps a mix of both. What technology clusters, i.e. technologies with interrelated usage patterns [3], are encountered in a high-technology firm? Do usage patterns vary across geographical divisions within the same firm? The objective of this paper is to uncover and compare technology clusters between two geographical divisions of a large Canadian telecommunication firm. The first sections review literature on ICT adoption, describe methodology and present the results. The last part consists of discussion and the conclusion.

2.0 Literature review

ICT adoption and diffusion is a two-stage process: first, adoption and implementation by the organization, followed by salesperson adoption and usage of these ICT. However, once ICT are adopted by an organization, it is the salespeople who are the ultimate adopters and users of the new ICT. Depending on their tasks and markets served, salespeople may make extensive use of a small number of ICT (high infusion) or else use a large number of ICT but tap only a few of their functions (low infusion). The actual usage pattern may lie between these two extremes and encompass a mix of mature and emerging ICT. Knowing that licensing rights may vary from US$10,000 to as much as $50,000 per seat, often a total expense of several million dollars, while failure rates may be as high as 60 to 80% [4], it seems only natural to explore the problem from the base, i.e. the end-user's perspective. To paint a better portrait of sales force usage of ICT, we used agglomerative hierarchical clustering (AHC) to group ICT with interrelated usage patterns.

3.0 Data collection

An electronic survey was sent to 228 potential sales representative respondents. Data was collected from 193 respondents, 107 from Quebec and 86 from Ontario, for an overall response rate of 85%. Respondents were asked to rate their usage of 32 ICT based on a seven point Likert scale (1 = never, 2 = very seldom, 3 = seldom, 4 = sometimes, 5 = often, 6 = very often and 7 = always). The ICT were selected

by   *Jozée Lapierre and Roxane G. Medeiros,*
École Polytechnic de Montreal, QC

Abstract

The information revolution has opened the floodgate to new innovations. With the advent of information and communication technologies (ICT), organizations are trying to stay afloat in these turbulent times. More than ever, these organizations are facing technological and market uncertainties and competitive volatility. To alleviate these disturbances, new sales channels have opened to meet customer's expectations. The sales function has drastically changed over the past 20 years in order to maintain this market orientation. Salespeople are now equipped with several ICT to accomplish their day-to-day activities. To better understand these changes, we investigate two geographical divisions - one in Quebec, the other in Ontario - of a large Canadian telecommunication firm. Using agglomerative clustering to segment 32 ICT according to usage frequency, we reveal sales force's usage patterns. The resulting technology clusters for each division are then compared to show the different mixes of mature and emerging ICT.

Sommaire

La révolution de l'information ouvre les vannes à toute une panoplie d'innovations. Plus que jamais, les organisations axées sur les hautes technologies font face à des incertitudes émanant des technologies et du marché ainsi qu'à une volatilité concurrentielle. Pour diminuer ces perturbations, de nouveaux canaux de vente sont ouverts afin de répondre aux exigences des clients. La force de vente a dû s'adapter durant les vingt dernières années afin de maintenir une orientation marché. Les représentants sont équipés de plusieurs TIC afin de pouvoir accomplir leurs tâches quotidiennes. Afin de mieux comprendre ces changements, nous étudions deux divisions géographiques, l'une au Québec, l'autre en Ontario, dans une grande firme de télécommunication canadienne. Une analyse de regroupement est utilisée pour segmenter les 32 TIC selon la fréquence d'utilisation. Les regroupements sont analysés et comparés afin de révéler les différences entre portraits d'utilisation.

from a list developed by the Centre francophone d'informatisation des organisations (CEFRIO 1999) and from the literature.

4.0 Sample characteristics

Age distribution between the two geographical divisions is markedly different, with 42.1% of salespeople being younger than 40 years old in Quebec and 72.1% in Ontario (p < 0.000). Salespeople in Quebec have a higher level of education, with 66.7% having a university degree, as compared with 53.5% in Ontario (p < 0.000). The national average for a university degree is 21.6% in Quebec and 24.7% in Ontario based on total population (national figures, 2001). Thus, the education level within the study firm is three times higher than the national average for Quebec and more than twice the average for Ontario. Experience also differs greatly, with an average of 15.5 years in Quebec and 7.8 years in Ontario. The time spent outside the office by salespeople does not dif-

fer significantly between the two divisions (p = 0.52). We therefore cannot rely on mobility to interpret the differences in usage patterns across geographical divisions.

5.0 Analytical procedures

For the purpose of this investigation, we used clustering analysis (CA) to group objects, the ICT themselves, as opposed to clustering salespeople as is traditionally done in marketing. To be realistic and since we had no a priori information as to how many clusters represent the best solution, we generated solutions for two, three, four, five and six clusters. To choose the best solution, we stopped clustering when there was a sharp decrease in the agglomeration coefficient. To confirm that we had identified the best solution, we used three methods, two intuitive and one statistical. The inverse scree test, a plot of the agglomeration level versus the number of clusters, showed a sharp nick in the curve at four clusters. The second intuitive method is based on our ability to name the cluster. What is the homogeneous characteristic underlying these technology clusters? Could we explain it? If yes, the solution was retained. If not, we looked at a different solution. The third, statistically-based method, Mojena's Rule, is a one-tailed t-test [5]. According to Mojena's Rule, usage patterns are best explained with a four-cluster solution for Quebec and Ontario, with significance levels $p < 0.05$ and $p < 0.04$, respectively. To compare usage patterns between geographical regions, we needed to know if we had distinct solutions. We therefore used the Rand index (r) to test the stability of the solution [6], where $r > 0.70$ indicates a stable solution and, conversely, $r < 0.70$ indicates an unstable solution. With $r = 0.59$, we have an unstable solution and thus two distinct usage patterns.

6.0 Results

Clusters are presented in Table 1 for Quebec and Table 2 for Ontario. For this preliminary investigation, we classified ICT as mature or emerging, in accordance with a discussion panel composed of other researchers involved in the technology management field. About half of the 32 ICT are qualified as mature: desk computer, printer, scanner, photocopier, fax, word processing, spreadsheet, database, CD-ROM, telephone, cellular phone, voice mail, pager, videoconferencing and file transfer protocol (FTP). The other ICT are classified as emerging and are mostly Internet-based: laptop computer, pocket PC, electronic message minder, computer imaging, presentation software, Internet, intranet, extranet, e-mail, chat, company web site, search engine, e-catalog, e-commerce, discussion forum, visioconference and CRM. Since no universally accepted classification was found in the literature, we believe that this classification is appropriate in this exploratory research.

Both regions have a very large cluster, the second one, and three smaller ones with markedly different cluster composition. In Quebec, Web-crawler contains 16 technologies (50%) and 12 of these are emerging ICT, while Messenger consists solely of mature ICT. In Ontario, Integrator is composed solely of emerging ICT, and the rest of the emerging ICT are more evenly distributed throughout the other three clusters. Interestingly, CRM is found in a small compact, spherical cluster containing only emerging ICT in Ontario. In Quebec, on the other hand, it is found in Webcrawler, the largest and one of the most eclectic cluster. Telephone and cellular phone, the two ICT that allow direct voice communication with customers, are found in the same cluster (Informer) in Ontario, and in two distinct clusters in Quebec (Processor and Demonstrator), respectively. Another interesting feature of these usage patterns is the cluster embedment. Integrator (search engine, CRM, extranet and Web site) in Ontario is embedded within Webcrawler in Quebec. Conversely, Processor (printer, e-mail, telephone, laptop, word processing and voice mail) in Quebec is embedded within Informer in Ontario. This embedment reveals that the Ontario division of the firm may be more progressive in its use of CRM. We believe that use of a small number of ICT may indicate in-depth usage of the functionalities (high infusion), as opposed to superficial usage of many ICT. Furthermore, the fact that CRM clustered exclusively with a few emerging ICT, while being clustered with mature ICT in Quebec, indicates that it may be used in a more integrated manner in Ontario. Since SFA and CRM tools are usually customized, it is not surprising to find markedly different usage patterns within the same firm for the two geographical divisions. Figure 1 presents usage patterns for both regions on the same graph.

7.0 Discussion

Our findings indicate that Ontario has a younger, well educated sales force and that Quebec's salespeople are more educated and more experienced. Younger, more educated salespeople will be the first to utilize SFA systems and make full use of their capabilities [7]. Clusters found in Ontario clearly show more progressive usage of ICT since one cluster consists solely of emerging ICT. In Ontario, emerging ICT are also more evenly distributed across the patterns than in Quebec, where 70% of them are found in a single, very large cluster. Being older, the sales force in Quebec may have already settled into work routines. This is reflected by Processor, the only cluster composed solely of mature ICT. Sales experience is another variable that may help explain cluster composition. Salespeople in Quebec average 15.5 years of experience, those in Ontario 7.8 years. Salespeople with less than five years of sales experience have a more positive attitude toward ICT and thus will use technology more fully [8]. This is further reflected in the more even distribution of emerging ICT across the clusters in Ontario, particularly by

Table 1: Clusters for Quebec

DEMONSTRATOR	WEBCRAWLER	PROCESSOR	MESSENGER
Presentation software	*E-catalog*	Printer	Fax machine
Pocket PC	CD-ROM	*E-mail*	Photocopier
Cellular phone	Database	Telephone	Videoconference
Pager	*Intranet*	*Laptop computer*	Desk computer
PDA	FTP	Word-processing	
Spreadsheets	*Internet*	Voice mail	
	CRM		
	Own company Web site		
	Computer imaging		
	Search engine		
	Forum of discussion		
	Chatroom		
	Extranet		
	Scanner		
	E-commerce		
	Visioconferencing		

LEGEND:
EMERGING: Italics
MATURE: Normal

Table 2: Clusters for Ontario

IMAGER	INFORMER	INTEGRATOR	NETWORKER
Computer imaging	Fax machine	*Search engine*	*E-commerce*
PDA	Spreadsheet	*CRM*	*Discussion forum*
Scanner	Voice mail	*Extranet*	Desk computer
Pocket PC	Printer	*Own company Web site*	
Chatroom	*Presentation software*		
Visioconferencing	Photocopier		
E-catalog	*Intranet*		
Videoconferencing	Telephone		
Pager	*Internet*		
Database	Word processing		
FTP	CD-ROM		
	E-mail		
	Laptop computer		
	Cellular phone		

LEGEND:
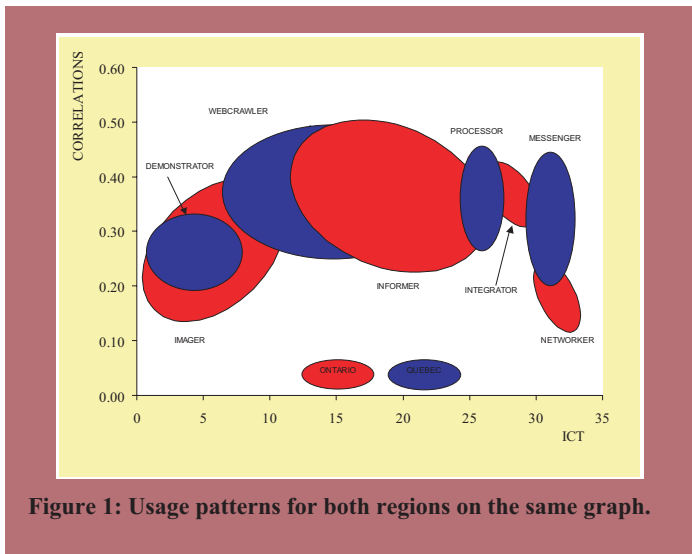EMERGING: Italics
MATURE: Normal

Figure 1: Usage patterns for both regions on the same graph.

Integrator the small cluster that includes CRM.

The discussion would be incomplete without mentioning the effects of culture when comparing mainly French-speaking Quebec and English-speaking Ontario. There are significant cultural differences at the societal level between Quebec and Ontario. Subcultural differences in Canada are important owing to multiculturalism and language. It is well established in marketing given the influence of the European founding cultures, the two linguistic subgroups differ significantly in their perceptions, attitudes and buying behavior [9]. Since salespeople can be viewed as individual consumers [7], we believe that these subnational differences in marketing between French speaking and English-speaking consumers are applicable to salespeople and are reflected in the different usage patterns between geographical divisions. Conversely, since both divisions offer the same products and services to customers in their respective regions, we think that these usage pattern differences may also be explained by the characteristics of the market served. As stated earlier, these differences in markets are in turn explained by cultural differences between English and French-speaking customers [9].

8.0 Conclusion and Managerial Implications

Our results suggest that the demographics of salespeople and national culture may explain the different usage patterns across two geographical divisions of the same firm. Clustering techniques are useful for uncovering ICT usage patterns among salespeople. Since these techniques provide a picture of which ICT are used in interrelated fashion, managers may find them highly valuable for purposes of implementation, training and recruitment. Clusters are useful for gaining a deeper understanding of the behavior of salespeople, a strategic human resource that can be described as the bread and butter of telecommunication firms facing strong competition. Clusters may be used as "diagnostic tools" to further improve the tasks (selling/non selling) technology fit, improve the alignment between salespeople ICT usage patterns and organizational goals and culture, and improve alignment between the ICT usage patterns of salespeople and customers. Using clustering as a strategic tool, managers will be better equipped to optimize ICT usage among mature and emerging technologies as well. We believe that this ICT fine-tuning between sales force and sales managers is one means of reducing implementation failure rates.

9.0 Acknowledgment

10.0 Acronyms

AHC	-	Agglomerative hierarchical clustering
CA	-	Clustering analysis
CRM	-	Customer relationship management
eCRM	-	Internet-based customer relationship management
ERP	-	Enterprise resource planning
ICT	-	Information and communication technology
IM	-	Integrated marketing
mCRM	-	Mobile customer relationship management
PRM	-	Partner relationship management
SFA	-	Sales force automation
SMA	-	Sales and marketing automation

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Approches heuristiques pour l'affectation de cellules aux commutateurs dans les réseaux mobiles

1.0 Introduction

Typiquement, un réseau cellulaire est constitué d'un ensemble de stations de base desservant les cellules et de plusieurs commutateurs connus sous le nom de Mobile Switching Centers (MSC). Dans de tels systèmes, la communication entre les usagers présents à l'intérieur d'une même couverture géographique se fait grâce aux liaisons câblées ou micro-ondes entre les stations de base et les MSC. Ainsi, les MSC gèrent la communication entre les usagers d'un même réseau et permettent également l'accès au réseau téléphonique commuté public. Les commutateurs ont la possibilité de se transférer la prise en charge d'un usager passant d'une cellule à une autre. Lorsque celui-ci passe d'une cellule à une autre, une mise à jour est effectuée au niveau des commutateurs concernés. Cette opération est connue sous le nom de relève (handoff). Si la relève a lieu entre deux cellules reliées au même commutateur, on parle de relève simple, car les mises à jour à effectuer sont peu nombreuses. En revanche, si cette relève s'effectue entre deux cellules reliées à des commutateurs distincts, on parle de relève complexe, les mises à jour impliquant plus de ressources dans ce cas.

Lorsqu'un usager est en mouvement dans une cellule, le signal analogique émis est aussitôt pris en charge par la cellule la plus proche. Il existe un seuil de sensibilité (ou seuil de filtrage) au-delà duquel le signal émis par l'usager est suffisamment puissant pour être pris en compte par la cellule.

Comme l'illustre la Figure 1, les cellules A et B relèvent d'un même commutateur 1, alors que les cellules C et D dépendent du commutateur 2. Un utilisateur présent en C pourrait émettre un signal suffisamment puissant pour être perçu simultanément par les cellules B et C compte tenu de la proximité des cellules, ce qui pose problème. Il faudrait se procurer un réseau de signalisation capable de juger quelle cellule reçoit le signal avec le plus de clarté et de déterminer ainsi le commutateur qui sera responsable de la communication. Dans le cas où l'usager quitte la cellule C et se retrouve dans la cellule D, on est en présence d'une relève simple. Seul le commutateur 2 est sollicité au cours de cette opération. En revanche, si l'usager passe de la cellule C à la cellule B, il y a une relève complexe. Les commutateurs 1 et 2 s'échangent l'information relative à l'usager et une mise à jour de la base de données du réseau est effectuée. Le coût d'une relève complexe est donc beaucoup plus élevé que celui d'une relève simple.

L'affectation des cellules aux commutateurs consiste essentiellement à trouver la configuration des liaisons commutateur-cellule qui minimise le coût total du réseau, en tenant compte d'un certain nombre de contraintes dont la fréquence des relèves entre cellules et la capacité de chaque commutateur. Parmi les facteurs qui doivent être pris en compte, on trouve la configuration du réseau, la capacité des commutateurs et le trafic acheminé par l'intermédiaire du réseau.

Considérons l'aspect de la configuration du réseau. Le problème
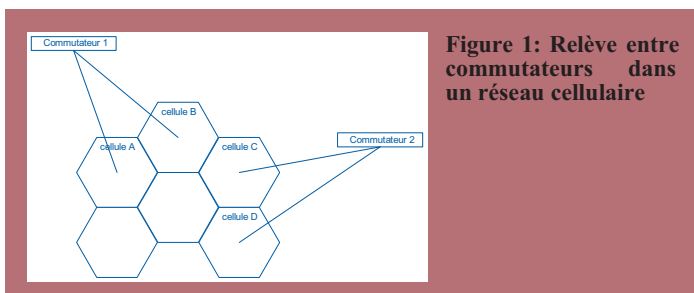
par   *Samuel Pierre, Alejandro Quintero & Agnès de Montgolfier, Département de génie informatique, École Polytechnique de Montréal, Montreal, QC.*

Abstract

For a set of cells and switches, the problem of cell assignment to switches in cellular mobile networks consists of determining a cell assignment pattern, which minimizes a certain cost function, while respecting certain constraints, especially those related to limited switch's capacity. The cost function integrates a link and a handoff cost component. Assigning cells to switches in cellular mobile networks being an NP-hard problem, enumerative search methods are practically inappropriate to solve large-sized instances of this problem. This paper presents the interaction between tabu search, simulated annealing and standard genetic algorithm to solve this problem. The implementation of these algorithms has been subject to extensive tests in order to measure the quality of solutions. The results obtained show that the simulated annealing and tabu search improve the individuals representing solutions provided by standard genetic algorithm.

Sommaire

Le problème de l'affectation des cellules aux commutateurs dans les réseaux cellulaires consiste, étant donné un ensemble de cellules et de commutateurs dont les emplacements sont connus, à affecter les cellules aux commutateurs de façon à minimiser une fonction de coût qui comprend une composante de coût de liaison cellule-commutateur et une composante de coût de relève. Cette affectation doit tenir compte de la contrainte de capacité des commutateurs qui ne peuvent supporter qu'un nombre limité d'appels. Un tel problème d'optimisation combinatoire est reconnu NP-difficile, ce qui justifie le recours à des méthodes heuristiques de résolution pour conjurer le risque d'explosion combinatoire. Cet article examine l'efficacité de différentes interactions entre trois méta-heuristiques bien connus jusqu'ici utilisés isolément pour résoudre ce problème: l'algorithme génétique, l'algorithme de recuit simulé et l'algorithme de recherche taboue. Les résultats obtenus de ces interactions montrent que les algorithmes de recuit simulé et de recherche taboue permettent d'améliorer les résultats obtenus par l'algorithme génétique.

revient, à partir de n cellules et de m commutateurs, à trouver un schéma d'affectation des n cellules aux m commutateurs qui minimise le coût total du réseau tout en respectant certaines contraintes. Si nous devions explorer de façon exhaustive tous les schémas d'affectation possibles (m^n dans notre cas) pour en choisir le meilleur, nous déboucherions rapidement sur un problème d'explosion combinatoire que même les ordinateurs les plus performants mettraient un temps excessivement long à résoudre.

Considérons maintenant l'aspect de la capacité des commutateurs. Il s'agit alors de réaliser les affectations en tenant compte du fait qu'un commutateur a une capacité limitée, c'est-à-dire que seul un nombre limité de cellules peut lui être raccordé. Cette capacité s'exprime en

Figure 1: Relève entre commutateurs dans un réseau cellulaire

volumes d'appels par unité de temps.

Considérons enfin l'aspect du trafic acheminé par l'intermédiaire du réseau. Ce trafic peut varier considérablement à deux moments de la journée. Ainsi, un schéma d'affectation efficace à un moment de la journée peut s'avérer inefficace à un autre moment. Il s'agit donc d'implanter deux affectations correspondant chacune à un moment de la journée. Il peut alors arriver qu'une cellule soit reliée à deux commutateurs différents, et cela doit être pris en compte dans le calcul du coût global du réseau.

Tout compte fait, la nature du problème demande une approche heuristique de résolution, ce que certains chercheurs ont déjà préconisé [4] [5]. Cet article examine l'efficacité de différentes interactions entre ces trois heuristiques. La section 2 expose brièvement le principe de fonctionnement de ces heuristiques. La section 3 définit les interactions entre l'algorithme génétique, le recuit simulé et la recherche taboue. La section 4 présente et analyse les résultats de simulation. La section 5, en guise de conclusion, résume nos principales observations.

2.0 Synthèse des méthodes heuristiques de résolution

Dans cette section, nous allons présenter brièvement les trois heuristiques utilisées: l'algorithme génétique, la recherche taboue et le recuit simulé.

2.1 L'algorithme génétique

Les algorithmes génétiques (AG) introduits par John Holland [2] sont fondés sur la théorie de la survie des espèces de Charles Darwin. Comme dans la nature où les êtres se reproduisent, dans le modèle des AG, les spécimens se reproduiront aussi; en particulier, ceux jugés les plus forts se reproduiront à un rythme plus rapide. Des opérateurs génétiques seront appliqués sur des candidats en espérant engendrer ainsi de nouveaux candidats plus performants [6] [7].

Dans la recherche de solutions à un problème, les AG utilisent une grande part de hasard. En effet, les candidats à la reproduction sont choisis de façon probabiliste. Les chromosomes de la population sont croisés de façon aléatoire dans la progéniture, et les gènes d'un chromosome sont mutés selon une certaine probabilité. En appliquant ainsi de génération en génération les opérateurs génétiques sur des candidats jugés performants, on cherche à obtenir une progéniture plus performante que celle de la génération précédente, ce qui permet de s'approcher ainsi d'une solution optimale.

2.1.1 Principe des algorithmes génétiques

Les mécanismes de base usuels sur lesquels repose la méthode des algorithmes génétiques sont principalement la représentation des chromosomes et les opérateurs génétiques. Un bon choix des paramètres de ces chromosomes assure la convergence vers une bonne solution.

Dans un AG, les chromosomes ont souvent une représentation binaire. Ce choix le rend intuitivement applicable à tous les problèmes dont les solutions sont transposables en binaire [6]. Les chromosomes sont alors représentés par une chaîne de bits. Cette représentation est indépendante du problème posé et rend l'algorithme génétique d'autant plus robuste.

Les opérateurs génétiques de base sont au nombre de trois: la **sélection**, le croisement et la mutation. La sélection est le processus selon lequel des chaînes de la population sont choisies pour une nouvelle génération d'après leur valeur par la fonction objectif. Plus la valeur de la fonction objectif est élevée, plus cette chaîne a de chances d'être sélectionnée. Notons qu'une des techniques les plus utilisées pour réaliser la sélection est celle de la roulette de casino: d'abord, on calcule la valeur d'aptitude de chaque chromosome, puis on calcule l'aptitude totale en faisant la somme des valeurs d'aptitude de chaque individu de la population; enfin, on calcule le pourcentage de chaque chromosome par rapport à l'aptitude totale.

Le **croisement** est le processus selon lequel les bits de deux chaînes sélectionnées au hasard sont interchangés: dans le langage génétique, on dira que ces chaînes sont croisées. Chaque paire de longueur t subit le croisement comme suit: une position entière k est choisie uniformément entre 1 et (t-1). Deux nouvelles chaînes sont créées en échangeant tous les gènes entre les positions (k+1) et t de chaque paire considérée. Les nouvelles chaînes peuvent donc être totalement différentes de leurs parents. Le croisement décrit se produit en un lieu, mais on peut aussi retrouver des croisements avec plusieurs lieux dans certains AG.

La **mutation** est le processus selon lequel la valeur d'un gène choisi au hasard dans un chromosome est régénérée. Ce processus ne survient qu'occasionnellement dans un algorithme génétique. En modifiant aléatoirement la valeur d'un bit dans une chaîne, la mutation est utile pour ramener du matériel génétique qui aurait été oublié par les opérateurs de sélection et de croisement.

De façon générale, un AG fonctionne de la façon suivante:

Étape 1: On génère une population initiale de taille n chromosomes, puis on choisit au hasard les gènes qui composent chaque chromosome: c'est la première génération de chromosomes.

Étape 2: On évalue chaque chromosome par la fonction objectif, ce qui permet de déduire sa valeur d'aptitude.

Étape 3: Le cycle de génération des populations commence alors, chaque nouvelle population remplaçant la précédente. Le nombre x de générations est déterminé au départ. Dans chaque génération, on choisit n chromosomes auxquels on va appliquer les différents opérateurs génétiques. Après chaque génération, les n nouveaux chromosomes créés remplacent la génération précédente.

Après la $x^{ième}$ génération, les chromosomes auront évolué de telle façon que cette dernière génération contienne des chromosomes meilleurs que ceux des générations précédentes.

2.1.2 L'algorithme génétique d'affectation de cellules

L'adaptation des algorithmes génétiques pour résoudre notre problème d'affectation de cellules aux commutateurs vise à trouver, à partir d'une population initiale de chromosomes, la meilleure affectation, c'est-à-dire celle qui minimise le coût du réseau tout en respectant la contrainte sur la capacité des commutateurs et celle d'affectation unique des cellules aux commutateurs. Dans un premier temps, il faut coder les solutions du problème afin de pouvoir le résoudre à l'aide d'un AG. La forme la plus répandue du codage est la représentation binaire où les gènes ne prennent que des valeurs 0 et 1. La représentation utilisée dans ce problème est cependant non-binaire. Chaque chromosome représente un schéma d'affectation spécifique. Les éléments de la chaîne représentant un chromosome sont des entiers, qui représentent les différents commutateurs numérotés de 1 à m. La Figure 2 donne un exemple d'un chromosome représentant un schéma d'affectation de 8 cellules à trois commutateurs.

La longueur des chaînes est égale au nombre de cellules et reste inchangée, car toutes les cellules du réseau doivent être affectées. De même, la valeur maximale d'un gène de ces chromosomes est égale au nombre maximal de commutateurs du réseau. La lecture des chromosomes se fait de gauche à droite; ainsi, le premier bit du chromosome contient le numéro du commutateur auquel la cellule numéro 1 est reliée. Le codage adopté permet de satisfaire une contrainte: celle de l'affectation unique des cellules aux commutateurs, car un gène d'un chromosome ne peut pas prendre simultanément plus d'une valeur. La seule contrainte à satisfaire reste alors celle sur la capacité des commutateurs.

1	2	2	3	1	3	2	3

Figure 2: Représentation non-binaire d'un chromosome

2.2 L'algorithme de recuit simulé

La méthode du recuit simulé (RS) a l'originalité de pouvoir s'appliquer à une grande variété de domaines et en particulier aux télécommunications. Le recuit simulé est une heuristique d'optimisation qui consiste en une recherche locale par perturbations. Ce processus donne la possibilité de s'éloigner occasionnellement d'un minimum local pour permettre ainsi un élargissement du champ de recherche de la solution idéale [3].

2.2.1 Principe de la méthode

Le recuit simulé est une procédure de recherche selon laquelle la topologie courante, retenue momentanément comme meilleure solution, est continuellement comparée à d'autres topologies qui lui sont très proches. Ces topologies voisines sont obtenues à la suite de petites perturbations sur la topologie courante. Lorsqu'une perturbation aboutit à une topologie meilleure que la solution courante, elle est sauvegardée comme solution courante. Cependant, il peut arriver que, suite à une perturbation, la topologie voisine obtenue soit conservée comme solution courante, même si elle n'est pas meilleure que la solution courante, à condition qu'elle respecte une certaine probabilité d'acceptation. Le fait d'accepter de temps à autre une solution dégradée permet d'éviter de s'enfermer trop tôt dans un minimum local. D'autre part, la probabilité d'acceptation doit être suffisamment faible, de telle sorte que l'algorithme puisse s'approcher le plus possible de l'optimum global.

En fin de compte, l'algorithme se termine lorsque le critère d'arrêt est satisfait. À cette étape, la recherche locale devrait avoir abouti à un minimum local ou à un optimum global. Il s'ensuit que la solution idéale trouvée est, soit localement optimale vu le nombre élevé de minima locaux, soit globalement optimale dans le meilleur des cas.

2.2.2 Affectation de cellules aux commutateurs avec l'algorithme de recuit simulé

Dans l'algorithme du recuit simulé, les paramètres en présence sont: la température θ, et le facteur de recuit α. Cet algorithme commence par générer une topologie initiale, chaque cellule étant affectée à un commutateur de façon aléatoire, sans se soucier des contraintes de capacité des commutateurs. En attendant, elle est sauvegardée comme première solution courante. Le paramètre θ est initialisé à une valeur θ_0 relativement élevée. On débute alors la boucle des perturbations. Cette boucle sera répétée tant que le critère d'arrêt n'aura pas été atteint. Notons que le critère d'arrêt doit être défini de manière à permettre la réalisation d'un maximum de répétitions de la boucle. En outre, la valeur du facteur de recuit α doit être choisie adéquatement pour éviter de décrémenter θ trop rapidement, ce qui rendrait moins poussée la recherche de la meilleure solution.

2.3 L'algorithme de recherche taboue

La méthode de recherche taboue (RT) est une technique adaptative introduite dans les années 70 en optimisation combinatoire pour résoudre les problèmes difficiles. Elle est considérée comme une métaheuristique, qui peut être utilisée pour résoudre différents types de problème [1].

2.3.1 Fondements de la méthode de recherche taboue

Présentons dans un premier temps l'algorithme de descente simple. Il part d'une solution initiale qu'il essaie d'améliorer de manière itérative. Pour cela, il génère à chaque étape un sous-ensemble V du voisinage N(s) de la solution courantes. Ensuite, il choisit dans cet ensemble V la meilleure solution, c'est-à-dire celle qui minimise la fonction objectif sur V. Cette dernière solution devient la solution courante et l'algorithme continue jusqu'au moment où aucun élément de V ne permet d'avoir une meilleure valeur de la fonction objectif.

La méthode de recherche taboue est une amélioration de l'algorithme général de descente. Elle essaie principalement d'éviter le piège des minima locaux. Pour cela, il est nécessaire d'accepter de temps en temps des solutions qui n'améliorent pas la fonction objectif, en espérant ainsi parvenir plus tard à de meilleures solutions. Cependant, le fait de vouloir accepter des solutions non forcément meilleures introduit un risque

de cycle, c'est-à-dire un retour vers des solutions déjà explorées. D'où l'idée de conserver une liste taboue T (tabu list) des solutions déjà visitées. Ainsi, lors de la génération de l'ensemble V des solutions voisines candidates, on enlève toutes les solutions appartenant à la liste taboue. Notons tout de même que, d'une part, le stockage de toutes les solutions déjà visitées peut nécessiter beaucoup de mémoire et que, d'autre part, il peut s'avérer utile de revenir à une solution déjà visitée pour continuer la recherche dans une autre solution. Un compromis a été adopté en ne gardant dans la liste taboue que les k dernières solutions. L'algorithme s'arrête quand aucune amélioration n'est intervenue depuis un certain nombre d'itérations ou si toutes les solutions voisines candidates sont taboues.

2.3.2 Affectation de cellules aux commutateurs avec la recherche taboue

La démarche adoptée consiste globalement à modifier itérativement une solution initiale en espérant aboutir à une solution finale respectant les contraintes du problème [5]. À cette fin, la méthode RT utilise des mouvements pour passer d'une solution à une autre à l'intérieur d'un espace de recherche prédéfini. Dans l'adaptation de la méthode RT, l'espace de recherche choisi est libre des contraintes de capacité sur les commutateurs, mais respecte la contrainte d'affectation unique des cellules aux commutateurs. La faisabilité de la solution finale n'est donc pas garantie, mais le fait de pouvoir examiner un plus grand nombre de possibilités augmente les chances d'aboutir à de bonnes solutions. RT associe à chaque solution deux valeurs numériques: la première est le coût de la solution, calculé à partir de la fonction objectif; la deuxième est une évaluation de la solution prenant en compte le coût et une sanction, sous forme de pénalité, pour le non-respect des contraintes de capacité, s'il y a lieu. À chaque étape, RT choisit la solution ayant la meilleure évaluation.

Contrairement à la méthode de descente, quand elle arrive à un optimum local, la méthode RT choisit la solution voisine qui dégrade le moins la fonction objectif. Pour éviter les cycles autour de cet optimum, une liste taboue garde les k dernières solutions et interdit momentanément un retour vers ces solutions. Les solutions sont libérées après k itérations ou lorsqu'elles satisfont un critère d'aspiration.

3.0 Interactions entre les heuristiques

Cette section expose les interactions des heuristiques que nous proposons pour la résolution du problème d'affectation des cellules à des commutateurs dans les réseaux cellulaires.

3.1 Interaction entre l'algorithme génétique et le recuit simulé

L'inconvénient principal de l'algorithme de recuit simulé (RS) est qu'il est appliqué à une topologie générée de façon totalement aléatoire. Ainsi, la solution à améliorer peut être une solution de coût très élevé ou une solution qui ne respecte pas les contraintes de capacité. Il serait donc préférable d'appliquer l'algorithme de recuit simulé à une solution que l'on sait faisable et, dans le meilleur des cas, de faible coût.

Nous voulons optimiser l'algorithme génétique en améliorant à chaque génération le meilleur chromosome de la population. Pour cela, à chaque génération, nous prélevons le meilleur chromosome de la population, nous lui appliquons l'algorithme de recuit simulé et nous obtenons une solution qui sera au moins aussi bonne que la précédente, puisque l'algorithme de recuit simulé ne peut produire qu'une solution de coût inférieur ou égal à celui de la topologie de départ. Nous obtenons ainsi un nouveau chromosome que nous insérons dans la population de l'algorithme génétique, à la place du chromosome de coût maximal, c'est-à-dire le moins bon chromosome de la population. L'algorithme général de cette version est présenté à la Figure 3.

3.2 Interaction entre l'algorithme génétique et la recherche taboue

Dans le cas de la recherche taboue, la solution de départ est créée en attribuant chaque cellule au commutateur le plus proche, en terme de
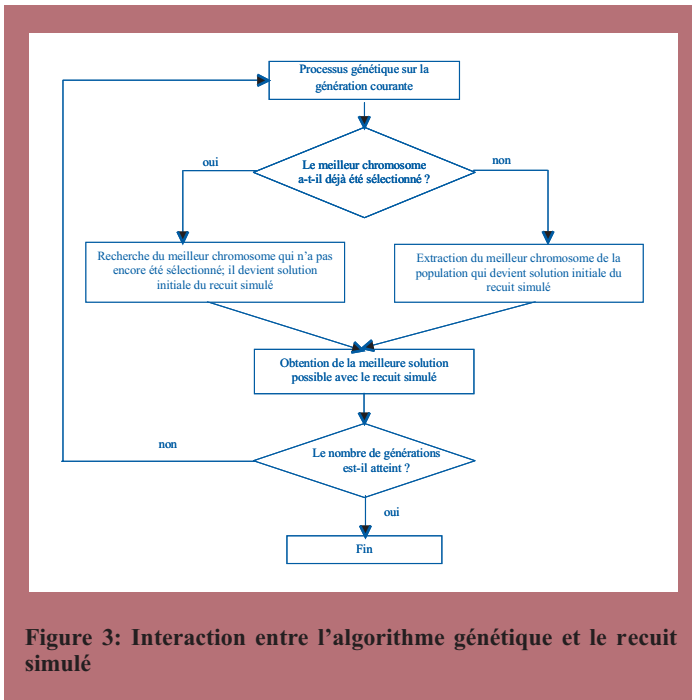
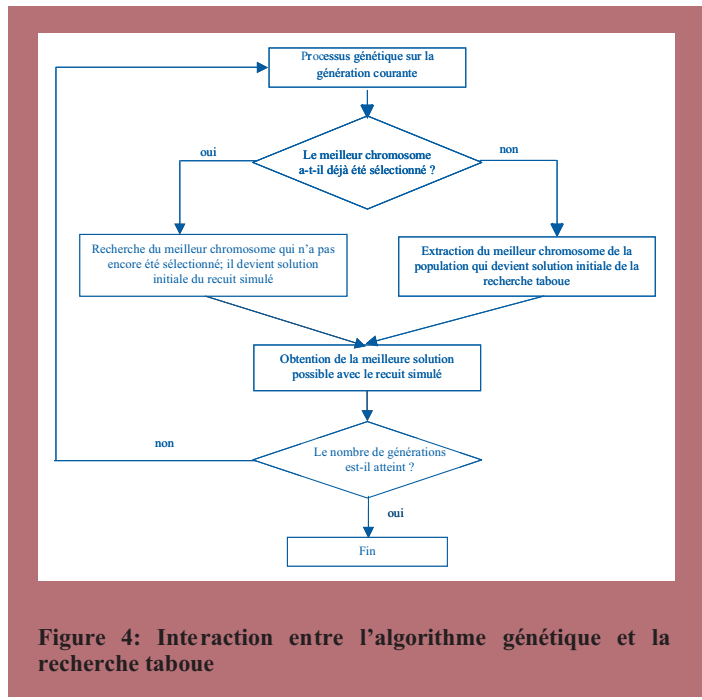**Figure 3: Interaction entre l'algorithme génétique et le recuit simulé**

Figure 4: Interaction entre l'algorithme génétique et la recherche taboue

distance. À chaque test, c'est donc la même solution de départ qui est fournie et la recherche taboue aboutira toujours à la même topologie finale. Donc, avec un même fichier de données initial, on ne pourra aboutir qu'à une seule solution finale.

L'idée est donc de générer la solution initiale à l'aide de l'algorithme génétique. Nous aurons ainsi à notre disposition une variété de solutions de départ et on peut espérer que l'algorithme de recherche taboue permettra d'atteindre d'autres minima locaux, voire le minimum global. Donc, l'idée est d'appliquer la recherche taboue à chaque génération de l'algorithme génétique. L'algorithme général est présenté à la Figure 4.

Nous voulons optimiser l'algorithme en améliorant à chaque génération le meilleur chromosome de la population. Pour cela, à chaque génération, on prélève le meilleur chromosome de la population, on lui applique l'algorithme de recherche taboue et on obtient une solution qui sera au moins aussi bonne que la précédente, puisque l'algorithme de recherche taboue ne peut produire qu'une solution de coût inférieur ou égal à celui de la topologie de départ. Nous obtenons ainsi un nouveau chromosome que nous insérons dans la population de l'algorithme génétique, à la place du chromosome de coût maximal, c'est-à-dire le moins bon chromosome de la population.

Dans cette deuxième interaction entre l'algorithme génétique et la recherche taboue, le processus génétique se fait à chaque génération de l'algorithme génétique. Une fois le processus génétique accompli, on s'intéresse au meilleur chromosome de la population courante. Si ce chromosome constitue une topologie qui a déjà été sélectionnée pour être solution initiale de la recherche taboue, on déplace notre choix sur le chromosome suivant, dans la population triée en ordre croissant des coûts des chromosomes, et ainsi de suite jusqu'à trouver le meilleur chromosome de la population qui n'a jamais été choisi pour être topologie initiale de la recherche taboue.

4.0 Implémentation et résultats

Nous présentons dans cette section les résultats obtenus des interactions entre les algorithmes présentées précédemment.

4.1 Algorithmes seuls

Dans un premier temps, on effectue une simulation sur chacun des algorithmes pris séparément afin d'avoir des solutions de référence. Les tests ont été effectués sur un ensemble de 900 topologies avec 3 réseaux différents: 100 cellules et 5 commutateurs, 150 cellules et 6 commutateurs,

et 200 cellules et 7 commutateurs. Pour chacun des algorithmes, nous avons effectué 20 tests pour chaque topologie différents et les valeurs présentées correspondent à une moyenne des 20 valeurs obtenues.

Afin de déterminer le nombre de générations qui permet d'obtenir le meilleur compromis coût obtenu/temps nécessaire, nous avons effectué des tests avec plusieurs nombres de générations. Les probabilités de croisement et de mutation ont été fixées respectivement à 0.9 et 0.08. La Figure 5 présente l'évolution du coût du meilleur chromosome de la population en fonction du nombre de générations de l'algorithme génétique pour un réseau de 100 cellules et 5 commutateurs.

Cela illustre le fait que le nombre de 500 générations permet d'aboutir à de bons résultats, en un temps acceptable. Avec 800 générations, on obtient des résultats un peu meilleurs, mais le temps nécessaire est plus élevé. Avec seulement 100 générations, les coûts de topologies obtenus sont élevés; le seul point positif est le temps d'exécution qui est faible. Avec 500 générations, le compromis atteint est bon; on atteint des coûts comparables à ceux atteints avec 800 générations, en un temps acceptable. Nous avons choisi donc d'effectuer les tests de référence avec un nombre de références égal à 500. Afin d'avoir en notre possession des valeurs de référence, nous effectuons des tests avec chacun des trois algorithmes pris séparément. Les résultats sont présentés à la Figure 6. Dans chacun des cas, la solution initiale est spécifique à l'algorithme:
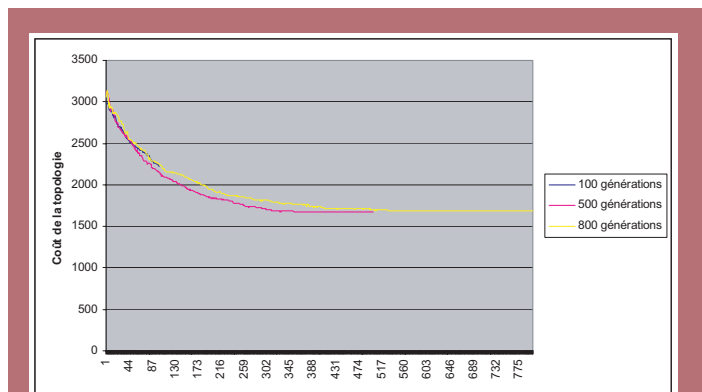

Figure 5: Évolution du coût du meilleur chromosome de la population en fonction du nombre de générations de l'algorithme génétique
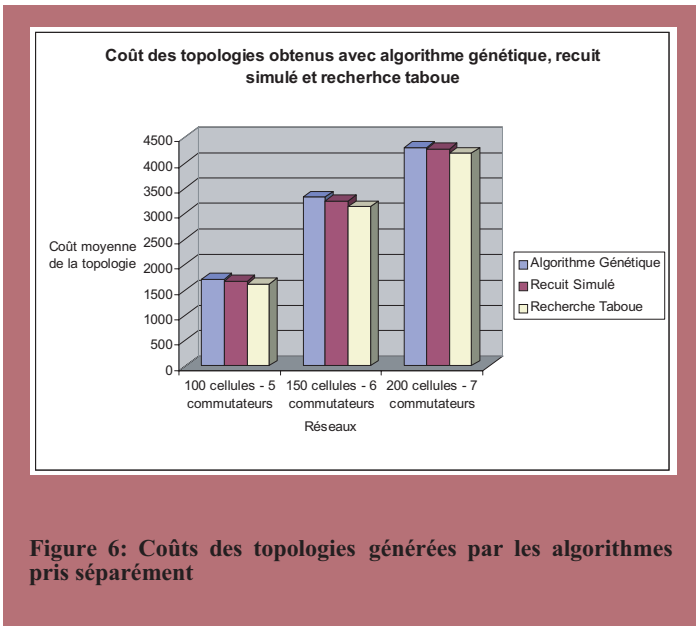
Figure 6: Coûts des topologies générées par les algorithmes pris séparément

Figure 7: Amélioration du recuit simulé et de la recherche taboue

elle est générée aléatoirement pour l'AG, aléatoirement également pour le recuit simulé et correspond à une affectation des cellules aux commutateurs les plus proches pour la recherche taboue. Il en résulte que les meilleurs coûts sont obtenus par l'algorithme de recherche taboue.

4.2 Interactions entre les trois algorithmes

Les tests ont été effectués sur un ensemble de 900 topologies avec 3 réseaux différents: 100 cellules et 5 commutateurs, 150 cellules et 6 commutateurs, 200 cellules et 7 commutateurs. Nous travaillons toujours sur une population de 100 chromosomes et nous réalisons les tests en faisant tourner l'algorithme génétique avec 100, 500 et 800 générations. Dans les trois cas, nous appliquons l'algorithme génétique, puis nous extrayons le meilleur chromosome de chaque génération qui devient la solution initiale du recuit simulé ou de la recherche taboue. Les paramètres utilisés sont une probabilité de croisement égale à 0.9 et une probabilité de mutation égale à 0.08. Pour le recuit simulé, nous utilisons un facteur de recuit égal à 0.7. Les résultats sont présentés à la Figure 7.

L'amélioration engendrée par le recuit simulé ou recherche taboue n'est pas significative lorsque l'algorithme génétique est effectué pendant 500 ou 800 générations. En effet, l'AG permet d'aboutir à des solutions acceptables, lorsque le nombre de générations est suffisamment élevé, c'est-à-dire quand il est égal par exemple à 500 ou 800. Deux hypothèses sont envisageables: soit on a atteint, grâce à l'algorithme génétique, un minimum local et l'algorithme de recuit simulé ou de recherche taboue ne permet pas d'en sortir, soit on a réussi à atteindre l'optimum global et, implicitement, l'algorithme de recuit simulé ne peut pas fournir une meilleure solution que celle déjà trouvée. Cependant, c'est la première hypothèse qui se trouve vérifiée. Or, on sait qu'il existe des topologies de meilleurs coûts que ceux-là, en se référant aux coûts trouvés par l'algorithme de recherche taboue. On peut donc en conclure que l'algorithme génétique, appliqué avec un nombre de générations suffisamment grand, permet d'obtenir une solution acceptable qui se situe dans le voisinage d'un minimum local; lorsqu'on applique le recuit simulé sur cette solution, on n'arrive pas à se dégager de ce minimum local.

En revanche, l'amélioration fournie par le recuit simulé et aussi pour la recherche taboue sur une solution générée par l'algorithme génétique, avec un nombre de générations faible, par exemple 100 générations, est relativement importante. En effet, en seulement 100 générations, l'AG ne permet pas d'obtenir une solution très satisfaisante; autrement dit, il ne trouve pas une solution dans le voisinage d'un optimum local. Par conséquent, lorsqu'on applique le recuit simulé ou la recherche taboue sur cette solution, il y a plus de chances de trouver une solution bien
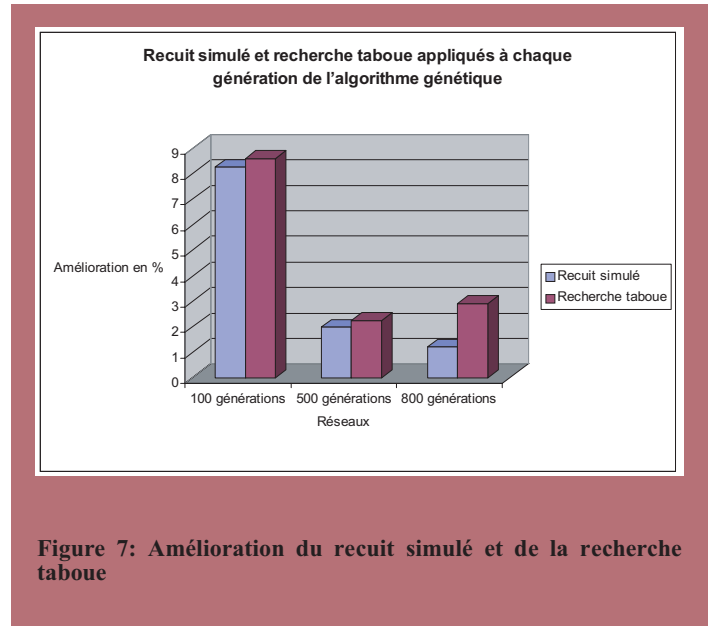
meilleure et donc de fournir une amélioration significative (Figure 8).

5.0 Conclusion

Dans cet article, nous avons étudié différents scénarios d'interaction entre trois heuristiques de résolution du problème d'affectation de cellules à des commutateurs dans les réseaux cellulaires mobiles. Nous avons donc conçu, implémenté et testé un algorithme génétique applicable à une population initiale, dans le but d'obtenir la solution qui minimise le coût du réseau, tout en respectant la contrainte d'affectation unique des cellules aux commutateurs et celle sur la capacité des commutateurs. Pour cela, nous avons d'abord conçu une procédure efficace pour la génération d'une population initiale sans doubles. Nous avons ensuite défini, implémenté et appliqué des opérateurs génétiques spécifiques au contexte de notre problème, opérateurs qui ont été appliqués par la suite à cette population initiale.

Tout compte fait, les algorithmes génétique, de recuit simulé et de recherche taboue constituent de bonnes méthodes pour obtenir des schémas d'affectation de cellules aux commutateurs qui sont de bonne qualité même s'ils ne sont pas optimaux. Toutefois, les résultats obtenus de ces interactions montrent que les algorithmes de recuit simulé et de recherche taboue permettent d'améliorer les résultats obtenus par l'algorithme génétique.
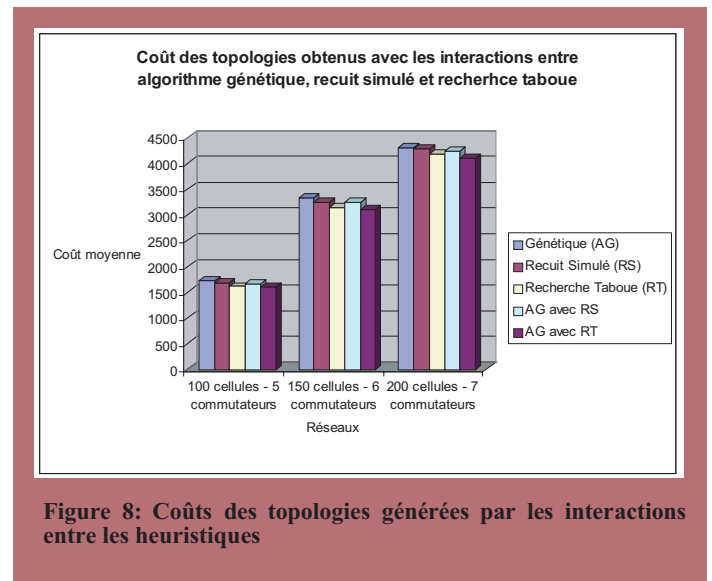
Figure 8: Coûts des topologies générées par les interactions entre les heuristiques

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Informal Meeting of Four National Engineering Organizations in Kingston

This self-defined group meets informaly a few times per year to share information and to ensure cooperation between the four national engineering organizations. The most recent meeting took place at the EIC offices in Kingston, Ontario on the 6th Nov. 2003.

From left to right: Claude Paul Boivin, CEO, The Association of Consulting Engineers of Canada, John Plant, Executive Director, Engineering Institute of Canada Marie Lemay, CEO, Canadian Council of Professional Engineers and Phillop Cockshutt, Executive Director, Canadian Academy of Engineering.

Claude Paul Boivin, CEO, ACEC and John Plant Executive Director, EIC close a cooperative agreement to share the EIC Career Site.

2003 IEEE Canada Vehicular Technology Conference Grant and Bursary

The IEEE Canada Student Activities Committee is very pleased to announce the recipients of the 2003 IEEE Canada Vehicular Technology Conference Grant and Bursary as follows:

- The travel bursary was awarded to Hamidreza Saligheh Rad, of Queens University, to attend the IEEE Semi-Annual Vehicular Technology Conference, VTC'04, May 2004.
- The research grant of $1500 was awarded to the RF and Microwave Electronics Research Group, Queens University, to support research on the Binary Phase Shift Keying (BPSK) Demodulator.

In supplement to the monetary award, the recipients will receive a letter of congratulations from IEEE Canada.

On behalf of the IEEE Canada Student Activities Committee, I thank all the Canadian IEEE Student Branch leaders and counsellors for promoting these awards in their schools.

Jorge Aguirre
SAC Awards Chair, IEEE Canada (Region 7)

On the Cooperative Control of Multiple Unmanned Aerial Vehicles

1.0 Introduction

Building upon rapid advances in robotics, control, communications and computer technology, UAVs will undoubtedly be called upon to play an ever-increasing role in the civilian and military communities. Military strategic planning has already started to incorporate wide-ranging roles for UAVs, such as tactical surveillance, communications relay, target designation, battle damage assessment and covert payload delivery [1]. In the future, teams of autonomous intelligent vehicles with common mission objectives will be integrated into military force structures. The problem of cooperative control of UAVs concerns the coherent and efficient maneuvering of each member of a group of aerial vehicles (the team) to successfully complete a mission with limited human intervention in a highly unstructured environment [2]. This can be achieved by devising control algorithms, implemented on digital hardware, that allocate tasks to each UAV member of the team, select flight paths and generate the trajectory for each member, and set attitude configurations to aerial vehicles at timely instants, at precise positions or during specific maneuvers such as evasion, combat, reconnaissance, take-off, landing, rendezvous and so on. The control objectives can be characterized as the optimization of a set of designer-specified global functions. A central motivation for the development of cooperative control schemes is that enabling UAV teaming should result in a more effective operational capability than that available through independent control of the UAVs. This idea, along with the need to leave it to a group of machines to effectively perform the dull, dangerous and dirty missions, are in fact the main drivers for the research in cooperative control today [3].

This article discusses some of the challenges currently faced by designers of cooperative control schemes for teams of UAVs, and presents possible solutions to the problems involved. An effective cooperative control strategy should provide close-to optimal, robust, real-time performance with a relatively fast response from the team. Specifically, decentralization of the cooperative control problem, to improve the team's robustness to failures and to reduce computing costs while satisfying global mission objectives, must be addressed. Team autonomy must be achieved via algorithms for the scheduling of tasks, the planning of vehicle paths and the generation of trajectories for each vehicle. Formulating a tractable optimization problem and effectively implementing cooperative control software with constrained inter-vehicle communications and computations, warranting real-time performance and a fast response, is critical. The latter is especially true for small-scale, expendable UAVs where lightweight, compactness and limited computing power and communications bandwidth are the norm. Finally, the article presents an experimental COTS testbed for the validation of the concepts and extensive testing in (quasi-) realistic scenarios.

2.0 Cooperative Control Of Multiple UAVs

Consider a set of $N \geq 2$ compact, light weight UAVs to be deployed either from a single location (ground or air) or from multiple locations. Each vehicle has its own intrinsic dynamic characteristics (time constants, aerodynamic coefficients, etc.), and computing, sensors, transmitters and actuators hardware. Hardware found on the vehicles is current and/or legacy technology. Prior to the UAVs being deployed, a certain level of information is assumed known and coded within each vehicle, such as information on the team members, the environment, the airspace and ground. Given a pre-specified list of global objectives, to be performed in a certain order and with certain constraints (on timing, location, fuel consumption, etc.), and limited knowledge, embedded in the on-board electronics of each UAV, of the environment (ground and air) and the team members, then the cooperative control problem can be described as follows:

To ensure the success of the team mission (in meeting global objectives) by appropriately (i.e. optimally) assigning tasks to each vehicle and planning the routes and actions of each vehicle (path planning, trajectory generation, low-level commands) in a cohesive manner (e.g. avoiding static and dynamic obstacles) despite disturbances (e.g. wind gusts) and uncertainties (e.g. limited information available to each vehicle).

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Abstract

Unmanned aerial vehicles (UAVs) are rapidly becoming a strategic asset of today's military forces and an enabler of transformation for the civilian airspace community. Cooperative teaming will revolutionize the employment of UAVs by replacing a single vehicle, currently controlled by multiple human operators, with teams of cooperating UAVs monitored (and/or controlled) by a single operator. Therefore, a cooperative control scheme for a team of UAVs will have to ensure the success of team missions by autonomously and optimally assigning tasks to each vehicle and planning the routes and actions of each vehicle in a cohesive manner despite disturbances, such as strong wind gusts, and uncertainties, such as the presence of unpredictable dynamic and static obstacles. Cooperative control software and hardware will have to provide real-time performance with a relatively fast response. To achieve such objectives, there are a variety of challenges that must be overcome by the designers. This article describes some of the issues and challenges currently faced by researchers and developers of tomorrow's teams of aerial robotic systems, and presents possible solutions to the problems at hand. Of particular interest to the electrical and computer engineering community are the issues of communications and computing demands that must be somehow constrained in the design of a multi-UAV cooperative control scheme. Finally, it is important to stress that cooperative control requires a synergy among a variety of disciplines for its effective solution, namely mathematics, computer science, engineering (control, aerospace, electrical, mechanical, communications, robotics), and operations research.

Sommaire

Les drones, ou avions sans pilote, sont maintenant devenus des atouts stratégiques des forces militaires et sont en voie de transformer l'espace aérien civil. La coopération entre drones va révolutionner leur utilisation. Présentement, un véhicule est contrôlé par plusieurs opérateurs. Dans le futur, un opérateur pourra surveiller (et/ou contrôler) plusieurs équipes de drones. Pour ce faire, une stratégie de contrôle d'une équipe de drones devra ordonnancer les tâches et planifier le vol (trajectoire) de chacun des drones de façon autonome et optimale malgré les perturbations, tel que de très forts vents, et les incertitudes, tel que la présence d'obstacles statiques et dynamiques imprévisibles a priori. Le logiciel et le matériel pour le contrôle coopératif devront rencontrer des exigences de temps réel et offrir des réponses relativement rapides. Pour accomplir de tels objectifs, il y a une multitude de défis qui doivent être relevés par les concepteurs. Cet article présente quelques-uns des enjeux et des défis auxquels doivent faire face les chercheurs et les développeurs des systèmes robotiques aériens de demain, et présente des solutions possibles aux problèmes courants. Les défis concernant les communications entre véhicules et les demandes en temps de calculs seront particulièrement d'intérêt pour la communauté d'ingénieurs en électrique et informatique. Finalement, il est important de souligner que solutionner le problème de contrôle coopératif de drones demande une synergie entre plusieurs disciplines, comme les mathématiques, l'informatique, le génie (commande, aérospatiale, électrique, mécanique, communications, robotiques), et la recherche opérationnelle.
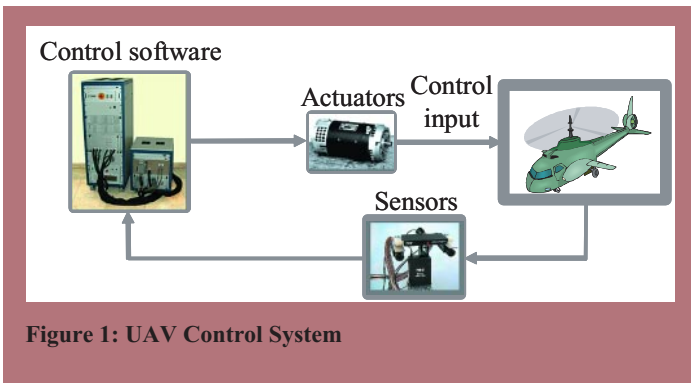
Figure 1: UAV Control System

Figure 3: Example of Task Allocation

The cooperative control problem is therefore a form of constrained optimization. The low-level UAV control system, such as the flight control system or autopilot/guidance (Figure 1). Figure 2 presents the schematics of a cooperative control scheme. The allocation of tasks, the planning of the path, the generation of the vehicle trajectories and the low-level control loop are feedback loops that are integral parts of the cooperative control strategy.
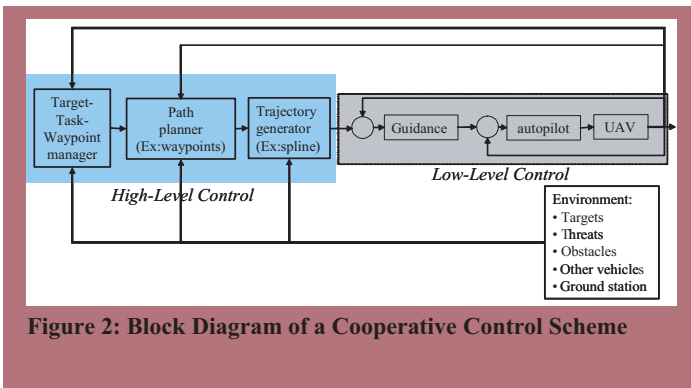

Figure 2: Block Diagram of a Cooperative Control Scheme

3.0 Team Autonomy In Task Allocation, Path Planning And Trajectory Generation

Team autonomy requires algorithms allocating tasks to team members, planning the path of each member and generating trajectories to ensure avoidance of static and dynamic obstacles (Figure 2) and such that prescribed target points are reached at some time instants. It must be emphasized that this procedure should be dynamic to react to changing conditions.

3.1 Task Allocation

To demonstrate a high level of autonomy, the UAV team receives a set of high-level orders from the ground control station (or has a set of pre-programmed orders) and deduces and manages a set of ordered tasks [4]. Task allocation can be exemplified as computing and assigning a set of waypoints to a sub-team of vehicles based on the information (vehicles states, waypoints locations, obstacles, etc.) known at mission pre-planning. However, as the mission is executed, the information about the environment, and the environment itself, will change. Thus, an optimal task allocation decided *a priori* to the execution of the mission will most likely become obsolete as the mission progresses, so the task allocation needs to be updated frequently during the mission. In addition, an approach obviating the need to re-consider the whole problem at once is necessary to avoid excessive computing demands on each vehicle. As suggested in [4], a sub-team problem can be solved, thus diminishing the computing demands, by involving only the vehicles having the largest influence on each other, such as those nearby the area of interest (e.g. close to a waypoint). Then, the task allocation can be based on a sub-team of UAVs, considering the local optimization problem within a prescribed 3D region.

The task allocation (or scheduling) problem can be stated as one of assigning a set of items or ordered tasks to each UAV such that an over-

all cost function is optimized while a maximum number of tasks is successfully accomplished, based on some knowledge of the environment. Due to the nature of this optimization problem (performing a search over all possibilities and obtaining the "best" solution is impractical), it is sometimes solved via heuristic techniques, such as greedy algorithms [5]. In general, heuristic techniques yield sub-optimal solutions to the problem at hand, although they provide finite-time computations, which increase in complexity as the number of vehicles and tasks increases (computing time increases as well). Graph theory can be used to model the problem, and integer programming can provide an algorithmic solution (Figure 3). In Figure 3, the problem is as follows. Given a set of waypoints/tasks, a 2-UAV team and the knowledge of the environment, perform the ordered set of tasks 1, 2, 3 and 4 as soon as possible.The numbers beside the arrows indicate path duration, the circles correspond to waypoints/tasks, the number of the task is in the top portion of the circle whereas the time required to perform a task is indicated in the bottom portion of the circles. The dotted lines correspond to the solution obtained with a heuristic method. It is clear that the time to execute the 4 tasks, in order, with the 2-UAV team is shorter than the time required with a single UAV.

3.2 Path Planning & Trajectory Generation

Path planning and trajectory generation can be tackled in combination. UAV trajectories are typically described by an ordered sequence of vehicle states, such as position and speed, over a certain time period. For example, the vehicle path can be based on the goal of reducing the exposure of each vehicle to ground threats, or to allow for the reconnaissance of several objects. With the knowledge of the waypoints and of the states of the nearby UAVs at these points, a trajectory generation algorithm then ensures that each UAV follows the prescribed trajectory. The algorithms must calculate trajectories that respect the vehicles' dynamics (constraints on vehicle states and allowed inputs) as well as the objectives of avoiding static and dynamic obstacles, and reaching a certain set of destinations at prescribed time instants. Specific trajectory profiles can be pre-programmed into each UAV, such as straight level flight or loitering-type flight. Trajectory generation should be updated at a rate fast enough to allow the UAVs to react, in real-time, to the dynamic environment. An approach allowing the UAVs to effectively react to the changing environment is the so-called receding horizon control strategy, where, at every sampling instant, an optimization problem is solved over a finite time horizon while considering updates of the optimization variables and the constraints. Figure 4 illustrates one approach to the combined path planning and trajectory generation problem for a single UAV. First, construct a grid of the region and obtain a set of best paths to reach the waypoints (i.e. intermediate waypoints) by using Voronoi diagrams [6], as shown in Figure 4(a). Second, generate a time trajectory, as shown in Figure 4(b). The challenge is to attribute flight paths to a team of UAVs in real-time and simultaneously.

4.0 Decentralization

A centralized approach in solving the cooperative control problem requires either a single vehicle with large computing capacity, to carry out the bulk of the computations, or a ground station equipped with heavy computing equipment, with which every vehicle in the team must be able to communicate. Either way, the communication costs are enor-

Figure 4: Path Planning & Trajectory Generation
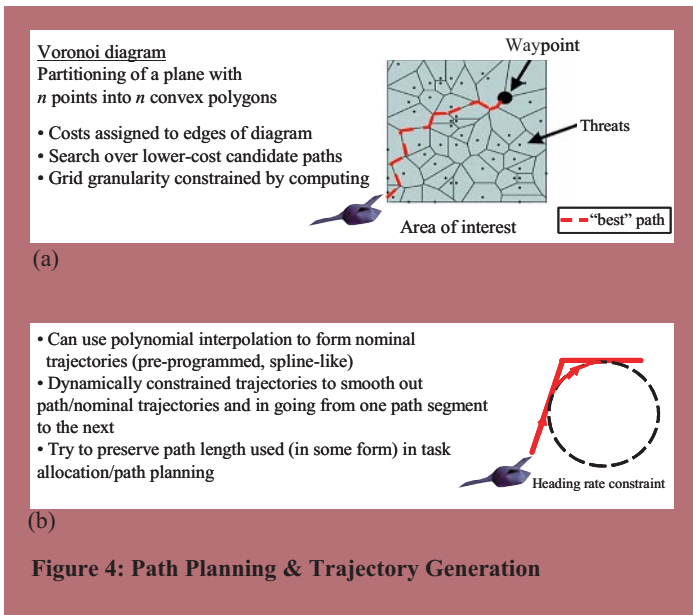
mous, and the lack of robustness of such an approach, that is the fact that the team is highly sensitive to failure of the main computing unit, is a major drawback. Figure 5 illustrates the centralized control of a 3-UAV team, where most of the computations are carried out on-board UAV 1. It is clear that failure of UAV 1 would jeopardize the success of the mission.

The alternative is decentralized control, where the solution to the optimization problem is decomposed into a set of N sub-problems, for instance one per UAV [7]. With decentralized control, the control and the data are distributed among the vehicles. Each team member has its own controller. While no one controller has enough local memory or computational power to solve the entire cooperative control, the team as a whole can. The controllers are somehow coupled, that is they share some information during flight. A major advantage of the decentralized strategy is the gain in the system's fault tolerance, as the robustness of the team to the loss of one or more UAVs during the mission is increased. However, the difficulty lies in determining 1) the decomposition of the original global optimization, 2) the information that should be exchanged among the UAVs, and 3) a way to warrant satisfactory team performance. Decentralization for a 3-UAV team is shown in Figure 6. Each UAV computes a portion of the entire cooperative control problem. The amount of data exchanged among the UAVs depends on the level of decentralization. A highly decentralized cooperative control approach requires minimal data exchanges whereas a lowly decentralized approach requires a maximum exchange of data (i.e. all of the available information). The trade-off between computing/communications costs and the level of decentralization is thus clear.

Figure 5: Centralized Control for a 3-UAV Team

Figure 6: Decentralized Control of a 3-UAV Team
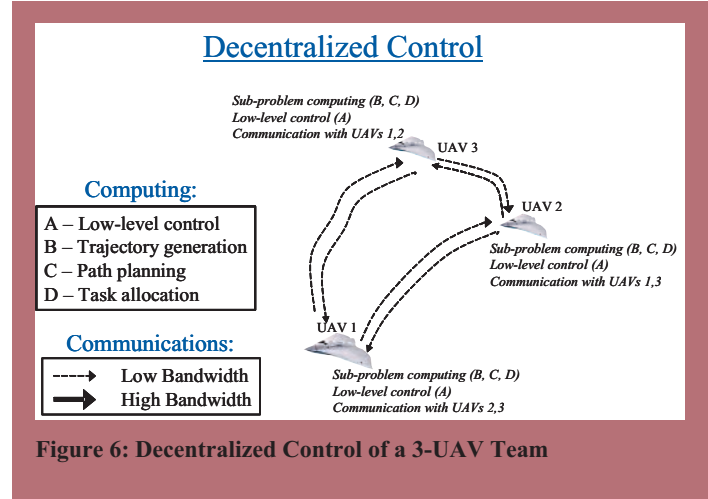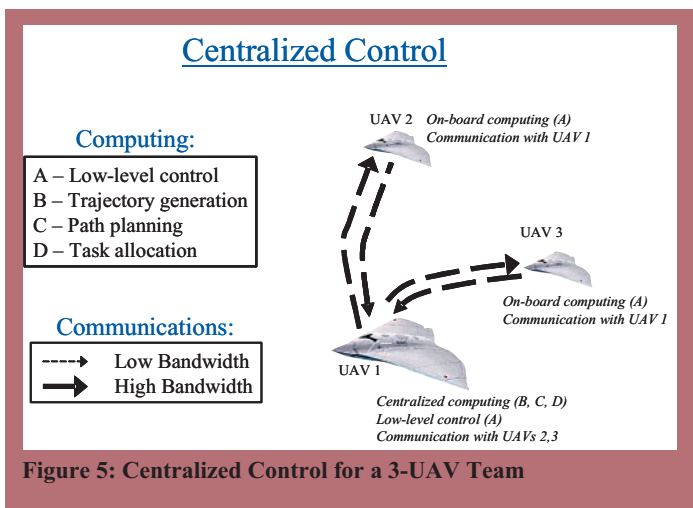
5.0 Computing & Communications

A major challenge with cooperative control, especially for teams with a relatively large number of UAVs, is the effective handling of the computations and the communications such that a fast response is obtained from the team. The control strategy should ideally result in real-time performance with control update and sampling rates that are relatively fast. By real-time execution, it is understood that the computations of the cooperative control algorithms and the communications are performed in a sequenced order at every iteration cycle over a predictable, bounded time period in an irreversible manner.

5.1 Computing

The sustained growth in computational processing power fosters a continuous evolution of control algorithms towards more complex, more capable, more robust solutions. However, UAVs' on-board systems will always have some limitation in regard to the implementation of complex real-time control strategies. Furthermore, in practice, designers strive for control strategies that provide real-time performance at the lowest costs, usually available with low-processing speeds hardware. In real-time control, overruns indicate that the actual execution of the real-time tasks, for each iteration step, has a longer duration than the sampling period. The designer must make sure that computing, communications and conversion times, for the given operating system (having its own figures of latency, jitter and task switching timings), digital hardware and input-output cards, can be performed within the sampling intervals selected to run the digital control algorithms. If overruns occur, then the designer may be forced to increase the sampling period and/or to redesign the control law. An alternative is to select a more powerful digital platform and/or communication medium, whenever it is possible. The issue of high computing demand associated with sophisticated UAV cooperative control strategies is well known [3]. The challenge thus lies in the design of an effective control system that works with the available hardware; that is, a control system warranting fast response as well as real-time performance. In small-scale UAVs, where light weight, compactness and low energy consumption are typical requirements, the control laws should generally be as simple as possible. There is therefore an expected trade-off between the performance level attained with a cooperative control scheme and the threshold on complexity, in both computing and communications. Ways of relaxing this trade-off include the combination of the cooperative control algorithms with real-time distributed and parallel processing within and among UAVs, and the use of dynamic task scheduling. Furthermore, the use of constrained UAV spatial horizons may enable a reduction in computing demands. Algorithm partitioning and distribution support heterogeneous processor architectures, thereby enabling the teaming of legacy UAVs. Figure 7 illustrates the concept of distributed computations for a team of 7 UAVs. At the given time step, 3 sub-teams are defined. The communications, needed to perform the distribution of the cooperative control problem among the UAVs, is shown with dotted lines. The intermittent communications that may arise between any sub-team and/or UAV and with a ground operator is not shown. Figure 7 shows the schematics of the parallel computing carried out within a 2-UAV team (that of UAV 3 and UAV 7), where the cooperative control algorithms are partitioned among the available hardware in order to provide reduced time step requirements and to use more efficiently the
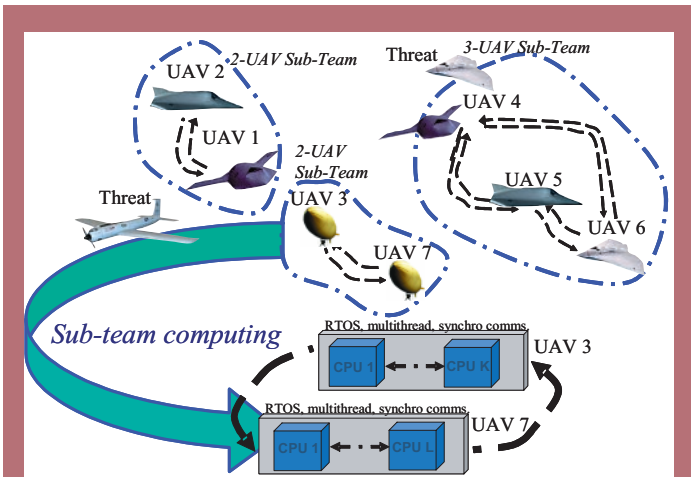
Figure 7: Distributed Computing within the 2-UAV Sub-team

computing resources. It should be noted that parallelism of the computations is achieved in two ways: first, within a UAV, provided it is equipped with a cluster of compact, low-power processors and DSPs connected in a parallel architecture, and, second, among the UAVs of a sub-team, when the inter-UAV communications required for such parallel processing are allowed. The partitioning of the algorithms can be done via heuristic methods, such as greedy algorithms, and more evolved Meta heuristics [5], and via feedback control concepts.

5.2 Communications

The various nodes (CPUs, DSPs, FPGAs, etc.) in a distributed real-time control system transmit messages to and receive messages from each other. A node may be a single UAV, a single CPU within a UAV, or a sub-team of UAVs exchanging with another sub-team of UAVs. There are inherent communication delays between nodes, which may vary due to network load, message priorities, and so on. Depending on the communications type, wireless Ethernet, RS-232, FireWire (IEEE 1394) or Giganet's cLAN for instance, there is a different probability distribution of the communication delays. The real-time operating system should be such that the interrupts are guaranteed to be handled within a certain specified maximum time. Figure 8 illustrates the communications that might be required with a cooperative control strategy not taking into account the requirement of constrained communications bandwidth. In the figure, the dotted lines constitute 2-way real-time communications between two UAVs. It should be noted that these communications are required to solve the real-time control problem without
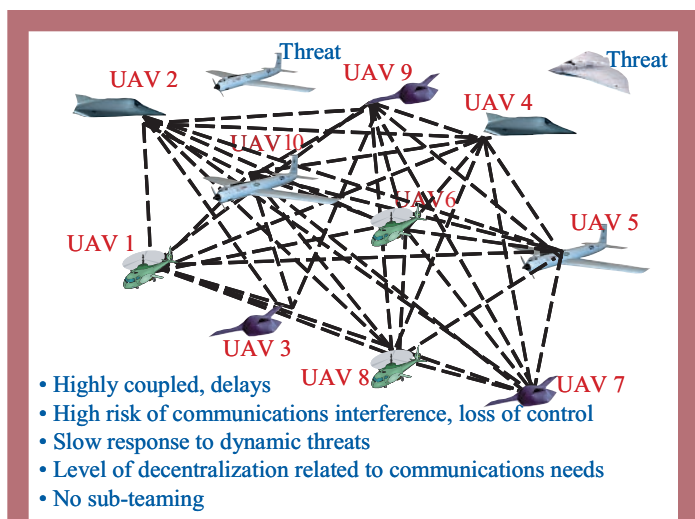
the notion of a sub-team. It is clear from Figure 8 that each UAV communicates, at every time step, with all of its teammates. Such exchanges will most probably result in communication delays, excessive use of communication channels and slow response to threats.

However, by adhering to a finite horizon strategy (i.e. a sub-team of vehicles which exchange data in real-time to solve a sub-optimization problem), communications among UAVs can be effectively constrained. In Figure 9, the spatial horizon of UAV i is given by a circle of radius r_i, i =1, 2, 3. At time step k, UAV 1 forms a sub-team with UAV 2; that is, UAV 1 is within the spatial horizon of UAV 2, and UAV 2 lies inside the horizon of UAV 1. Therefore, UAVs 1 and 2 share data in real-time to solve a common optimization and to calculate their respective paths, via parallel computing. It should be noted that the optimization problem for UAVs 1 and 2, at time step k, considers the union of the regions covered by the horizons of both UAVs 1 and 2, which includes UAV 3, as seen in Figure 9. Another sub-team is that of the single UAV 3, which does not receive information from the other two vehicles to compute its path since they lie outside of its horizon. Still, UAV 3 could share information with the rest of the team in an ad-hoc, intermittent fashion.

6.0 Experimental Validation

Commercial software such as Matlab/Simulink[TM] provides an effective modeling and simulation framework in which to test the cooperative control approaches. With such software, the vehicle dynamics, the interactions among the vehicles and with the environment, and the control laws can be modeled. Furthermore, a variety of test scenarios and fault/uncertain conditions can be implemented and simulated. For example, operationally relevant mission scenarios (e.g. littoral surveillance and interdiction) and performance metrics (e.g. persistence of sensor-coverage over targets, and percentage of targets found) can be verified. In the simulation studies, dynamic aspects should include random time-critical targets and behavior that necessitates team adaptation. Performance metrics should include measurements of the UAV team cooperation and interaction levels. Analysis can be performed to determine how to trade-off performance with team size, on-board processing power and available inter-UAV bandwidth.

Despite the importance of modeling and simulation in the cooperative control design process, control laws can only be truly verified with an experimental testbed involving actual on-board UAV electronics and (quasi-) realistic operating conditions. Figure 10 presents an experimental set-up where an actual small-scale UAV mock-up (remote controlled aerial vehicle) sits on a platform that comprises a set of load cells. These instruments measure the forces acting on the airframe for various commands of aileron, elevator, rudder and motor speed. The cells are connected to a digital computer via acquisition cards and converters. The feedback loop then involves measurement of forces (and computations of moments) for the generation of appropriate commands to the

Figure 8: Full Bandwidth Communications

Figure 9: Constrained Bandwidth Communications

PWM motors. The cluster of processors does not only provide control laws for the single UAV mock-up (low-level autopilot, guidance system, and so on), but also comprises a set of modeled and simulated UAV dynamics and controls, working in real-time, and exchanging useful data with the UAV mock-up, when appropriate computing power is available. Real-time execution of a large number of complex dynamic systems can be accomplished by the implementation of the control and simulation processes on a cluster of PCs connected in parallel. For instance, Figure 10 presents the multi-processor architecture with a representative real-time communication network infrastructure. The CPUs contain processes that provide real-time simulation of the UAVs (airframe dynamics, digital electronics, sensors, actuators) and the environment. The CPUs are connected via a fast communication link, such as FireWire. The architecture of the cluster must be such that the processes running on the various CPUs execute in parallel, thereby optimizing the computing resources available and enabling real-time computing and communications at relatively short time steps. External hardware, such as actual UAVs, can be connected to the cluster and synchronized exchanges assured via appropriate cards and drivers. The experiments and simulations can be monitored and modified, on-the-fly, via the host PC. On the host PC, simulation results can be interpreted and conditions of operation can be altered.

7.0 Conclusions

The paper described some of the issues and challenges involved in the design of effective schemes for the cooperative control of UAVs and proposed solutions that are currently being investigated. Of particular interest are the issues of communications and computing demands that must be constrained in the design of a multi-UAV cooperative control scheme; for instance, by using inter-vehicle communications governed by receding spatial horizons and parallel computing. The availability of low-cost digital processors, communications media and small-scale airframes of the fixed-wing and rotorcraf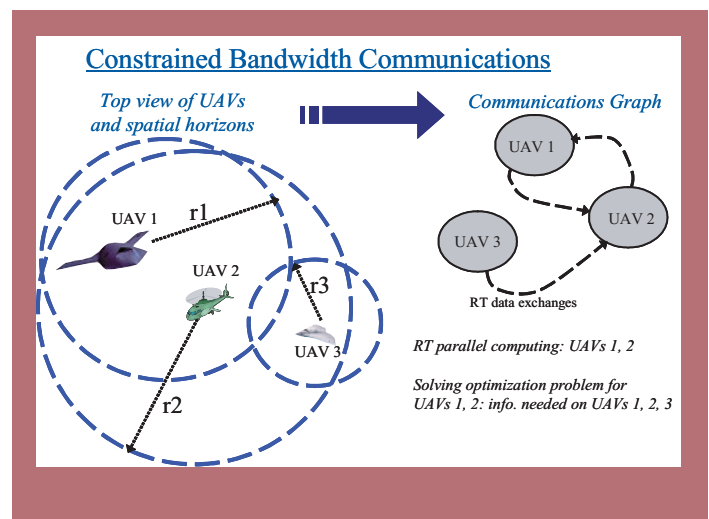t types has rendered the demonstration of cooperative control of multiple aerial platforms feasible. However, the algorithms implemented on the hardware platform are really the key to the success of a cooperative control strategy. Therefore, it is hoped that the article made clear the following point: the cooperative control of multiple UAVs is a challenging problem that requires a synergy between a variety of disciplines for its solution. It is believed that communications and sharing of knowledge among engineers and scientists will enable the development of effective multi-vehicle cooperative control strategies in a not-so-distant future.

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Figure 10: Experimental Set-up for Multi-UAV Control

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CRM Package Implementation in a Multi-National Bank

1.0 Introduction

Globalization, the internet, lower customer transaction switching costs and more sophisticated customers are factors that are tilting the balance of power in favor of customers. In today's digital economy, companies are realizing that the customer is really in charge and that building and sustaining competitive advantage by focusing on customer value driven strategies is not only good business but also imperative.

According to a recent Financial Post poll of 656 CEOs around the world, customer loyalty or retention was identified as the top management issue. In the Canadian context, an Andersen Consulting Customer Relationship Management (CRM) survey of 204 business leaders found that retaining market share and loyalty of customers is the number one reason for pursuing a CRM strategy. Additionally, this same study found that 80% of respondents polled indicated they could be at risk without a CRM strategy.

Management researchers focusing on marketing established some time ago that it is much more cost effective to sell a product or service to an existing customer than to a new customer. Frederick Reichheld of Harvard Business School showed the significant positive impact of customer loyalty and retention on profitability [1]. In today's e-business world in which companies operate, customers are fickle, their expectations high and competition is just a click away. It is therefore not surprising to find that business leaders are striving to find innovative ways to excite and delight their customers.

CRM as a strategy is on the radar screen of the executive brass. Consequently, many CIOs are now considering CRM implementation projects and this trend is surely going to rise in the future. Today the CRM product landscape is competitive and includes products such as PeopleSoft's CRM, Siebel Systems CRM On Demand, Oracle's E-Business Suite, SAP's mySAP CRM and a number of midmarket players such as Microsoft, Onyx and Pivotal. A study by AMR Research concluded that the CRM segment of the enterprise application market is the fastest growing at 35 percent annually and is expected to reach $21 billion by 2004 [2]. With the growing interest in CRM as a business strategy for meeting corporate objectives, it is important for managers and practitioners to understand what approach to use in order to plan for CRM projects to be successful. Most CRM software vendors and IT service organizations are strong proponents of the "out-of-the-box" approach whereby only minor modifications are made to the CRM application in order to quickly implement the software. However, it is important to note that empirical evidence on the positive impact of such an approach on CRM project success is lacking. The purpose of this article is to demonstrate that a CRM implementation project can be successful without necessarily adopting the *de facto* "out-of-the-box" approach.

2.0 CRM Overview - A Primer

CRM is about optimizing existing customer relationships, creating mutually beneficial interactions that attract new customers and increasing customer value at every opportunity [3]. It is not just about implementing sales force automation, call centers and marketing analysis though each of these component solutions is an important piece of the larger puzzle. Implementing CRM can be complicated as it may involve managing the customer interaction at every touch point (e.g., bank branches, automated teller machines, point-of-sale devices, self-service web sites, electronic mail, call center). Bringing together disparate customer data from many parts of the organization and across traditional and electronic channels is an important prerequisite for successfully implementing a CRM strategy [4]. Keeping this customer profile information current so as to present the customer with a consistent view of the company is the other necessary and non-trivial prerequisite. Customer information is key and can be used for different purposes allowing a company to:

- Reduce overall marketing costs by developing and executing more effective targeted campaigns,

by   **Karim K. Hirji**

     AGF Management Ltd., Toronto, ON

Abstract

Customer relationship management (CRM) focuses on keeping customers and building a strong relationship with them, thus enhancing customer loyalty. This article describes a CRM package implementation project at a major Canadian bank that is focusing on increasing customer satisfaction among its large corporate, mid-market and small business customers. Most CRM software vendors and IT service organizations suggest adopting an "out-of-the-box" approach to quickly implement CRM software. However, following such a generic approach is dangerous because it can lead to wasted resources, missed opportunities and ultimately project failure. The analysis of the case study presented in this article suggests an alternative approach that can be used to quickly implement CRM software. This approach involves organizing the CRM package implementation project to focus on four interdependent areas - business objectives, data architecture, application architecture and technology infrastructure.

Sommaire

La gestion de la relation client (CRM) met l'accent sur le développement d'une solide relation avec les clients, augmentant ainsi leur loyauté. Cet article décrit un projet d'implantation de CRM réalisé pour une importante banque canadienne qui préconise l'augmentation de la satisfaction de la clientèle d'affaires, de mid-market et de petites entreprises. La plupart des vendeurs de logiciel CRM et des organisations de service de technologie de l'information suggèrent d'adopter l'approche "out of the box" pour une implantation rapide. Cependant, appliquer une approche générique comporte plusieurs dangers qui peuvent se traduire en gaspillage des ressources, en occasions manquées et, éventuellement, en l'échec du projet. L'analyse de l'étude de cas présentée dans cet article propose une alternative pour l'implantation rapide de logiciel CRM. Cette approche veut que le projet d'implantation du CRM soit organisé de telle sorte qu'il mette l'emphase sur quatre aspect interdépendants: les objectifs d'affaires, l'architecture des données, l'architecture d'application et l'infrastructure de la technologie.

- Increase customer satisfaction and retention by enabling front-line employees to be more responsive to customers,
- Increase sales by offering products and services that meet the wants and needs of its best customers,
- Streamline customer communication, and
- Realize a higher net income from continuing operations by increasing profitability per customer and sale.

2.1 Building Customer Relationships

Customers are willing to build a relationship with a company when two conditions are met [5]. First, the sum of product or service-related benefits must be positive and greater than the associated total costs. Second, the net benefits must be superior to other alternatives available from competing firms. From the perspective of the firm, the relationship must be economically viable.

Relationships can exist at a personal level, company level and brand level. The case of exchanges between a patient/physician, investor/advi-

sor, student/teacher and mentor/mentee are examples of personal level relationships because of the high degree of intimate contact. An interaction between an individual and a company as a whole is a company level relationship where product standardization and less intimate customer contact are the norm. Examples of this type of relationship include purchasing an airline ticket, shopping at a grocery store or eating at a fast food restaurant. Finally as the term brand loyalty suggests, a relationship can exist between an individual customer and a specific brand. Think for a moment about Coke, Nike and the mutual funds that make up your investment portfolio.

3.0 Case Study and Analysis

A single-site research design was chosen for this study as it provided a unique opportunity for in-depth analysis [6]. The data collection for this study was carried out in multiple steps using several sources of information - minutes of meetings, project plans, customer deliverables and internal company documents. Direct observation was used during field visits to the case study site to collect observational evidence.

An important pragmatic requirement in this study was to find a company willing to participate. The commercial banking division of a leading full-service financial institution operating in Canada and the US provided the CRM implementation project for detailed analysis. At the time of this study, ABC Bank was undergoing considerable change as a result of marketplace pressures. One significant and strategic initiative was to improve the customer experience with ABC Bank. The commercial banking division was viewed as a leader in adopting and deploying leading edge solutions thus it was not surprising to find it at the forefront in embracing CRM.

As part of its drive to improve the customer experience at ABC Bank, a new call center was being established to service small business, midmarket and large corporate customers. The purpose of this new call center was to support the new streamlined business processes of servicing commercial banking customers. The CRM implementation project was referred to as the call center project and received direct sponsorship and funding from the line of business executives. Additionally, this project received technical sponsorship from the director of CRM initiatives.

The call center project began in mid July 2000. The commercial banking division had just completed a CRM vendor selection initiative in June 2000 whereby Siebel 2000 Finance was selected as the CRM software for implementation. Additionally, an external systems integration firm was selected to implement the Siebel CRM software. At the end of the project, the sponsors evaluated the implementation as an unqualified success because it met the critical and immutable production live date of mid-December 2000.

Once the project team was assembled, a kick-off meeting was held to identify the implementation approach. The "out-of-the-box" approach was critically evaluated and subsequently dropped as an option mainly because of the significant mismatch between the new business processes of servicing commercial banking customers and the inherent business interaction model depicted in the Siebel software. Taking the "out-of-the-box" approach would have meant redesigning the business processes from scratch to adopt the Siebel model as a standard.

The principle behind the alternative approach is to not have the CRM technology alter the new streamlined commercial banking business process model but rather to seek an implementation where the technology would support the new way of interacting with customers. To accomplish this, four sequentially interdependent areas were identified. Knowing the Business Objectives is the starting point in this approach and the basis for evaluating, designing and establishing the data architecture, application architecture and technology infrastructure. The Business Objectives area focused on identifying, understanding and supporting the objectives of the call center project.

Data Architecture is concerned with identifying and capturing the necessary data to support the Business Objectives. Key data elements to support the business process model at various points in time were identified and later provided as a requirement to the application architecture. With the data elements identified the Application Architecture focused on customizing the Siebel CRM software. Various "out-of-the-box"

CRM is about optimizing existing customer relationships, creating mutually beneficial interactions that attract new customers and increasing customer value at every opportunity [3].

screens, views and Siebel interaction model relationships were changed to ensure that the application captured, processed and presented the necessary data to support the streamlined way of doing business. Finally, Technology Infrastructure is concerned with optimal selection and placement of technology components such as servers, networking equipment and monitoring software to support both the use of the CRM software and exchange of data between the call center application and other business applications.

4.0 Conclusion

Developments in communications technology, advances in transportation, the emergence of the Internet and reduced trade barriers are some of the forces leading companies to rethink how to "do business" in the 21st century. Today, the unwavering commitment to the customer is essential for organizational survival and consequently CRM initiatives are on the rise. In concept CRM is simple. It is the process of predicting customer behavior and selecting actions to influence that behavior to benefit the company. This article focuses on exploring a CRM implementation project in the commercial banking division of a Canadian bank and the main finding that there is an alternative to the "out-of-the-box" approach to implementing CRM software is important for practitioners and managers. The results of this study provide an important planning consideration for similar projects both in other lines of business within banks (i.e., retail banking, wealth management and corporate banking) and in other areas of the financial services sector - namely securities, insurance and wealth management.

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HSDPA: An Overview

1.0 Introduction

The requirements for future wireless communication systems are rapidly evolving as applications increase in complexity. Many users require access to real-time applications, the internet, and high speed file transfer on a regular basis. To meet the demanding throughput and delay requirements of these services, the 3rd Generation Partnership Project (3GPP) has developed a new high speed data transfer protocol named High-Speed Downlink Packet Access (HSDPA).

In the 3GPP standards, Release 4 specifications of this protocol provide efficient IP support enabling provision of services through an all-IP core network. Release 5 specifications focus on HSDPA to provide data rates to support packet-based multimedia services. HSDPA is evolved from and is backward compatible with Release 99 WCDMA systems. Following feasibility studies in 2002, the wireless industry is in trial mode to implement HSDPA in the near future.

HSDPA is expected to provide a significant performance increase over the 2 Mbps data transfer capabilities of WCDMA. Throughput is expected in excess of 10 Mbps, increasing to nearly 20 Mbps when combined with a Multiple-Input Multiple-Output (MIMO) antenna structure. The substantial increase in throughput is realized by means of a fast link adaptation scheme that will utilize Adaptive Modulation and Coding (AMC). This protocol operates by transmitting with a constant power, while the Modulation and Coding Scheme (MCS) is altered to match the instantaneous channel conditions experienced by the User Equipment (UE). If errors occur in the transmission process, Hybrid Automatic Repeat reQuest (HARQ) is employed to quickly retransmit packets at the link layer. Finally, fast scheduling is used to quickly schedule users when experiencing a constructive fade, maximizing throughput and reliability to these users.

2.0 Physical Layer

To facilitate operation of HSDPA, three new channels have been added to the WCDMA platform. These channels include the High-Speed Downlink Shared Channel (HS-DSCH), High-Speed Shared Control Channel (HS-SCCH) and the Uplink Dedicated Physical Control Channel (DPCCH). The following sections discuss these channels in detail.

2.1 High Speed Downlink Shared Channel (HS-DSCH)

The HS-DSCH is the primary radio bearer for this technology. As the name suggests, this channel is provisioned as a shared resource for all users in a particular sector. During each transmission slot, users are assigned an MCS level that will maximize throughput, while maintaining a low probability of retransmissions.

Primary channel multiplexing occurs in the time domain, where each Transmission Time Interval (TTI) consists of three timeslots, totaling 2 ms. The selection of a 2 ms TTI has resulted in several benefits over the 10 ms TTI used for data transfer with WCDMA. This includes reduced round trip delay and higher validity of the channel estimation mechanism. For instance, if a longer TTI is combined with AMC, more channel variations will occur during the transmission, possibly corrupting the data packet.

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Abstract

High Speed Downlink Packet Access (HSDPA) is a packet-based data service in W-CDMA downlink over a 5 MHz bandwidth. It is intended to provide higher capacity, reduced delay and significantly higher data rates. This article first describes its physical layer and then discusses four important implementations of HSDPA. They are: Adaptive Modulation and Coding (AMC), Hybrid Automatic Request (HARQ), Fast Scheduling and Fast Cell Selection (FCS).

Sommaire

HSDPA est un service de données qui est basé sur la transmission de paquets en downlink W-CDMA sur bande passante de 5 MHz. Ce service a pour objectifs d'offrir une plus grande capacité, une réduction des délais et des taux de transmission des données plus élevés. Cet article décrit les couches physiques et les quatre importantes implantations du HSDPA. Les implantations du HSDPA sont les suivantes: modulation adaptative et code (AMC), demande automatique hybride (HARQ), ordonnancement rapide et sélection cellulaire rapide (FCS).

Within each 2 ms TTI, a constant spreading factor of 16 is used for code multiplexing, providing a maximum of 15 parallel channels for the HS-DSCH. These channels may all be assigned to one user during the TTI, or may be split amongst several users. The number of parallel channels allocated to each user depends on cell loading, QoS (Quality of Service) requirements, and the capabilities of the UE.

2.2 High Speed Shared Control Channel (HS-SCCH)

The HS-SCCH is used to signal a variety of information to the UE before the beginning of each scheduled TTI. This includes the channelization-code set, modulation scheme, transport block size, and HARQ protocol information. Although all of this information is required to successfully decode the data on the HS-DSCH, the channelization-code set and the modulation scheme are time critical parameters. These identify which parallel codes on the HS-DSCH contain data for the UE, and whether QPSK or 16-QAM is used in the upcoming transmission. If this data is not received before the beginning of the HS-DSCH TTI, the data will be buffered until the UE is aware of these parameters. This increases the delay and buffering requirements considerably. One might imagine that this could be solved simply by sending all this information prior to the TTI. This, however, will increase the delay between the channel quality feedback and the transmission, reducing the validity of
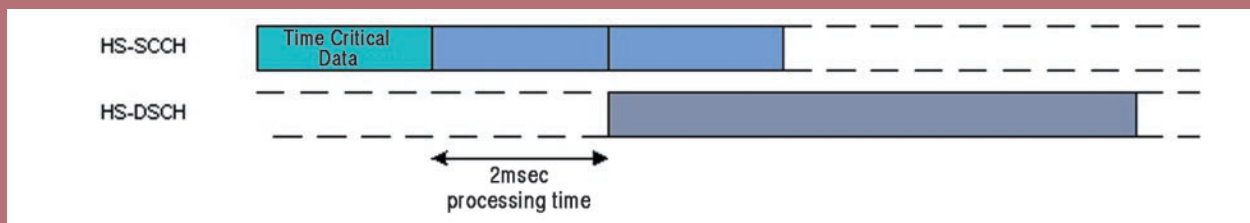

Figure 1: Timing Relation

the channel estimation process. As a result, the 3GPP has elected to separately interleave the time critical data, and send it in the first 0.667 ms slot of the HS-SCCH. Figure 1 shows this timing relation.

Since this channel is only required prior to the HS-DSCH TTI, it is favorable to provide a shared resource for this purpose. For this reason, the UE must monitor between one and four HS-SCCH channels simultaneously. An HS-DSCH Indicator (HI) is then sent on the users Dedicated Channel (DCH) to indicate the control channel that contains data for the UE. By sharing this resource, less power is required for signaling, increasing the system's efficiency considerably.

2.3 Uplink Dedicated Physical Control Channel (DPCCH)

The third new channel required to implement HSDPA is the Uplink DPCCH. This channel is responsible for uplink signaling of Acknowledgements (ACK) and Negative Acknowledgements (NACK) to indicate the status of the previous packet. The Channel Quality Information (CQI) is also sent on this channel. A five bit value is used to indicate which modulation and coding schemes are suitable for the upcoming transmission. Different codes indicate MCS levels ranging from QPSK using R = ¼ turbo coding, to 16-QAM with R = ¾ turbo coding. One state is also reserved to indicate that no transmission should be made in the event of extremely poor channel conditions.

3.0 Adaptive Modulation and Coding

Adaptive Modulation and Coding is the fundamental technology that allows HSDPA to surpass the data rates of its predecessors. Traditionally, systems that utilize Code Division Multiple Access (CDMA) have used a constant modulation scheme (usually M-PSK), with fast power control to adapt to changes in channel conditions. Instead, AMC transmits with a constant power while the Modulation and Coding Scheme is altered to adapt to these variations. This results in higher average throughput because higher order MCS levels are assigned to users experiencing favorable conditions. Spectral efficiency is also increased because the highest possible MCS level is utilized during each transmission.

The selection of the MCS level is done to maximize throughput, while maintaining a low probability of retransmission. In effect, if a user is experiencing favorable channel conditions, a high order modulation scheme such as 16-QAM with R = ¾ turbo coding may be used to maximize throughput for this user. Conversely, if the channel conditions are poor, QPSK with R = ¼ turbo coding can be used to provide higher reliability in the transmission. Further granularity is accomplished by using code rates from ¼ to ¾ with the previously mentioned modulation schemes.

The MCS level used in the upcoming transmission is selected based upon the power measured on the Common Pilot Channel (CPICH). The UE then encodes the data and transmits this CQI on the DPCCH. The UE is then scheduled by the Node B (base station controller), where the final selection of the MCS level and channelization-code set is performed. This functionality is located at the Node B to ensure that fairness is retained between users, and the majority of QoS requirements can be satisfied.

4.0 Hybrid Automatic Repeat Request

Although the MCS level is selected to ensure a reasonable probability of a successful transmission, errors do occur in any wireless system. This is a result of highly variable channel conditions caused by interference from other users and base stations. Under normal circumstances, approximately 10 - 30% of first transmissions must be resent to be successful. For this reason, the choice of the retransmission protocol is vital to the performance of any wireless communication system.

The 3GPP selected HARQ for retransmissions because of its ability to quickly retransmit packets. HARQ functionality is implemented at the MAC (Media Access Control) layer, as an alternative to the RLC (Radio Link Control) layer used for many other data transfer protocols. This decreases delay considerably because this entity is located at the radio interface. In normal instances, a negative acknowledgement may require less than 10 ms at the MAC layer, while this process may take between 80 and 100 ms at the RLC layer while the information is sent over the network interfaces [4].

By decreasing the delay associated with retransmissions, protocols such as TCP/IP can be easily implemented into higher layers of the system. This will allow support for a variety of applications, such as the inter-

net and file transfers, which already rely on TCP/IP for higher layer error correction and flow control.

To limit the complexity of the retransmission process, the 3GPP has selected the Stop-and-Wait (SAW) protocol. This operates by transmitting one packet and awaiting a response from the UE. The problem, however, is that the system is idle while awaiting acknowledgements. To reduce this inefficiency, the 3GPP has selected an N-Channel SAW protocol. While one channel is awaiting an ACK or NACK, the other (N - 1) channels continue to transmit. Although the value for N is still being evaluated for performance and complexity, it is expected to be between two and four.

Another benefit of HARQ is that it uses a three stage virtual buffer to store a soft copy of the previously transmitted packet. When a retransmission occurs, the data is combined with data stored in the soft buffer to effectively increase the coding gain. This enables the retransmission process to require fewer transmissions, and increases the average throughput as a result.

The method of combining packets with those stored in the soft buffer is very important to the performance and complexity of the retransmission process. Two fundamental schemes have been proposed to accomplish this task. These include Chase Combining (CC) and Incremental Redundancy (IR).

Chase Combining is the least complex combining scheme; however, it provides a lower coding gain than IR. The Node B simply retransmits the original packet, and the UE combines this with data stored in the soft buffer.

The IR schemes, however, provide additional coding gain by transmitting parity bits in the retransmission. The result is that fewer retransmissions are necessary to successfully retransmit packets. This is especially true under poor channel conditions, or when the user is traveling at a high velocity.

5.0 Fast Scheduling

The fast scheduling entity is also very important in the operation of HSDPA. One primary change from the previous implementations is that the scheduler is located at the Node B. This enables the scheduler to quickly respond the changes in the channel conditions, and ensures that the UE is served while on a constructive fade. There are three main types of schedulers that have been proposed for HSDPA. These include Round Robin (RR), Maximum C/I, and Proportional Fair (PF).

The RR scheduler operates by scheduling users based upon their position in a first-in first-out queue. Although this scheduler provides the least complex operation and the most fairness between users, the UE's channel conditions are not taken into consideration. As a result, users may be scheduled when experiencing a destructive fade, causing the packet to be corrupted.

As an alternative, the Maximum C/I algorithm schedules users when their instantaneous SIR is the highest amongst all users at the respective base station. This scheduling algorithm ensures that all users are served on a constructive fade, and as a result, has a higher percentage of successful transmissions. Also, the throughput and spectral efficiency is maximized because the highest possible MCS level is used during each transmission. The disadvantage, however, is the lack of fairness between users in the sector. In normal circumstances, the geometry of radio propagation causes nearly 50% of users to be located near the cell border. This indicates that nearly half of the users may receive inadequate service as a result.

A compromise between these two schedulers is the Proportional Fair algorithm. This schedules users based on the offset between the long term average SIR and the instantaneous SIR. The result is that each user is served while on a constructive fade, while fairness is maintained because instantaneous channel conditions will exceed the long term average at some instant. Figure 2 shows the operation of the previously discussed scheduling schemes.

6.0 Fast Cell Selection

In any cellular communication system, handoffs are necessary to accommodate users that are in motion, or those located near the cell border. Traditionally, CDMA systems have utilized a soft handoff procedure to seamlessly switch between base stations. The scheduled nature of the HS-DSCH, however, makes it impossible to use a soft handoff mechanism with HSDPA. Instead, a fast, hard handoff algo-
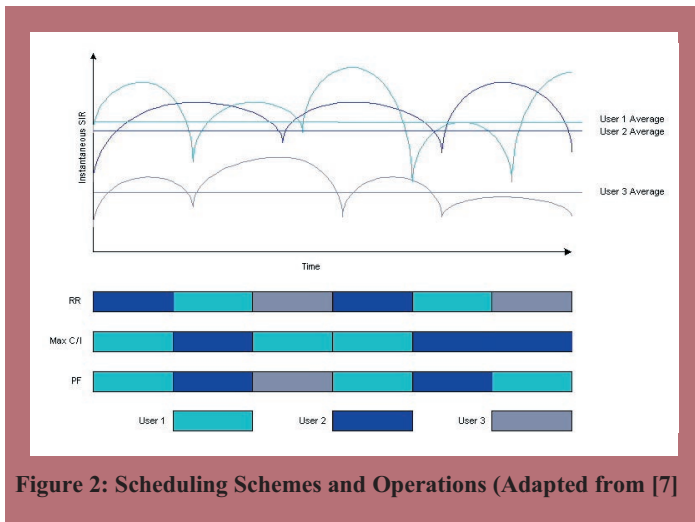
Figure 2: Scheduling Schemes and Operations (Adapted from [7]

rithm has been proposed to quickly switch between base stations.

This technology, named Fast Cell Selection (FCS), operates by monitoring the SIR level of all the base stations in the UE's active set. When a different base station in this set can provide a higher SIR (higher CPICH power), the user is transferred to the respective base station.

Both Internode and Intranode handoffs can be supported with FCS. When utilizing Intranode B FCS, the fast handoff mechanism is restricted to base stations that are a subset of the current Node B. If a sector outside of the current Node B can provide better channel conditions, the RNC (Radio Network Controller) is responsible for the handoff procedure. This increases the handoff delay considerably, and may result in QoS requirements that cannot be satisfied. The alternative to this restriction is to utilize Internode handoffs. Internode B FCS allows the UE to quickly change base stations regardless of the respective Node B. This decreases the delay in the handoff procedure; however, complexity is increased considerably. When a handoff occurs, the UE must use over-the-air signaling to quickly signal its status to the new Node B.

This technology has proven to be beneficial in providing seamless coverage to mobile users. It also increases performance to users located near the cell border, especially when combined with the RR scheduler. Less benefit is realized, however, when implemented with a Maximum C/I scheduler because users located near the cell border are rarely serviced.

7.0 Conclusion

The future of cellular communication is an ever expanding marketplace. As applications increase in complexity, the resources that support these applications will need to evolve as well. The 3GPP's evolution in high speed data transmission will definitely be a good candidate in providing users with the increased data rates and minimal delay necessary to support these applications. Only time will show the actual benefit of HSDPA, but at the present time, it appears to be a viable protocol for the future of cellular communications.

8.0 Read more about it:

[1]. 3GPP RAN TS 25.848 v4.0.0 (2001 - 03). "Physical Layer Aspects of UTRA High Speed Downlink Packet Access (Release 4)", April 5, 2001.

[2]. 3GPP RAN TS 25.950 V4.0.0 (2001-03), "High Speed Downlink Packet Access (Rel. 4)", Mar. 27, 2001.

[3]. T.E. Kolding, F. Frederiksen, and P.E. Mogensen. "Performance Aspects of WCDMA Systems with High Speed Downlink Packet Access (HSDPA)", Proc. of 56th IEEE VTC, September 2002. pp 477 - 481

[4]. M. Chatterjee, G.D. Mandyam, S.K. Das. "Fast ARQ in High Speed Downlink Packet Access for WCDMA Systems", Proc. of European Wireless. February 2002. pp 451 - 457.

[5]. A. Das, F Khan, A. Sampath, and H. Jung Su. "Design and Performance of Downlink Shared Control Channel for HSDPA", Proc. of 13th IEEE PIMRC, Sept. 2002. pp 1088 - 1091.

[6]. M. Dottling, J Michel and B. Raaf. "Hybrid ARQ and Adaptive Modulation and Coding Schemes for High Speed Downlink Packet Access". Proc. of 13th IEEE PIMRC, Sept. 2002. pp 1073 - 1077.

[7]. Y. Ofuji, A. Morimoto, S. Abeta, and M. Sawahashi. "Comparison of Packet Scheduling Algorithms Focusing on User Throughput in High Speed Downlink Packet Access", The 13th annual symposium on Personal, Indoor and Mobile Radio Communications, 2002. Sept. 2002. pp 1462 - 1466

9.0 Acknowledgement

10.0 Acronyms

3G	-	Third Generation
3GPP	-	Third Generation Partnership Project
ACK	-	Acknowledgement
AMC	-	Adaptive Modulation and Coding
CDMA	-	Code Division Multiple Access
CPICH	-	Common Pilot Channel
DPCCH	-	Dedicated Physical Control Channel
FCS	-	Fast Cell Selection
HARQ	-	Hybrid Automatic Repeat Request
HSDPA	-	High Speed Downlink Packet Access
HS-DSCH	-	High Speed Downlink Shared Channel
HS-SCCH	-	High Speed Shared Control Channel
MAC	-	Media Access Control
MCS	-	Modulation and Coding Scheme
NACK	-	Negative Acknowledgement
PSK	-	Phase Shifting Key
QAM	-	Quadrature Amplitude Modulation
RLC	-	Radio Link Control
RNC	-	Radio Network Controller
TTI	-	Transmission Time Interval
UE	-	User Equipment
WCDMA	-	Wideband Code Division Multiple Access

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Effets optiques des structures périodiques

1.0 Introduction

Les structures périodiques démontrent certaines propriétés optiques intéressantes. La propagation de la lumière est un phénomène spatial et de ce fait elle associe les trois dimensions x, y (transversales) et z (propagation) dans une harmonie physique maintenue par le principe de conservation de l'énergie en toute position longitudinale z de l'espace. La périodicité, parce qu'elle présente un lien spatial dans le plan transversal (x, y), permet à l'association mentionnée ci-dessus d'être à l'origine d'effets optiques intéressants observés à des distances particulières z. Nous allons décrire ces effets et certaines de leurs applications tout le long de cet article.

Dépendamment de la nature (spatiale ou temporaire) des structures périodiques et de leurs modes d'éclairage (cohérent ou incohérent), on distingue 3 phénomènes que nous allons traiter dans des sections séparées: Effet Talbot spatial [1], Effet Talbot temporel [2], Effet Lau [3].

Étant donné que la périodicité est une condition nécessaire pour les trois effets, nous allons lui consacrer une sous-section à part pour discuter la façon dont on peut assurer cette contrainte. En effet, nous pouvons réaliser cette contrainte lors de la mise en œuvre même de l'objet. Dans ce cas, l'objet à éclairer par la lumière sera périodique par défaut. C'est le cas par exemple d'une diapositive contenant une photo répliquée périodiquement le long des axes x et y. Une alternative consiste à éclairer un objet non périodique et créer la périodicité optiquement par un système approprié. Dans ce cas, l'objet initial présentera une seule période. Toujours avec l'exemple de la diapositive comme objet, nous pouvons imaginer qu'elle contient une seule photo.

Les structures périodiques ont des applications directes dans le monde des télécommunications optiques. En effet, la structure périodique peut être un front d'onde ayant une forme périodique comme elle peut être un morceau de fibre optique ayant un indice de réfraction changeant périodiquement le long de ce morceau (réseau de Bragg). En outre, la périodicité peut être temporelle. C'est le cas d'un signal sous forme d'un train d'impulsion qui se propage à travers une fibre monomode. Enfin, l'intérêt des structures périodique se manifeste également lors de la mise en œuvre d'autres structures périodiques essentielles en télécommunications. C'est le cas de l'utilisation des éléments diffractifs périodiques pour la réalisation des réseaux de Bragg.

2.0 Effet Talbot Spatial

L'effet Talbot, ou l'auto-imagerie cohérente des structures périodiques, découvert par H. Talbot en 1830 est un phénomène qui a suscité l'intérêt d'un grand nombre de chercheurs et d'ingénieurs. Des recherches intensives [1], y compris les nôtres [4], ont été menées ces dernières décennies afin de mieux comprendre et ainsi d'exploiter pleinement les différents aspects de ce phénomène. L'effet Talbot basé sur la théorie scalaire de la diffraction est capable d'expliquer diverses observations. Cet effet spatial a ouvert la porte vers beaucoup d'applications: les Illuminateurs de tableaux, guidage d'ondes, antennes, interférométrie, photolithographie, métrologie optique, traitement d'image, imagerie 3D, opérations logiques,…

2.1 Reproduction intégrale

Le phénomène de diffraction impose que la valeur en un point (x_0, y_0, z) quelconque du champ diffracté à une distance z soit la somme des contributions de tous les points (x, y, 0) du champ initial. Certes, le caractère de périodicité dans le champ initial implique que les points particuliers (x, y, 0), séparés les uns par rapport aux autres par un multiple de la période d le long de l'axe x ou y, auront à part un déplacement latéral, des contributions identiques. Ceci fait que l'on observe le champ initial se reproduire intégralement à des distances d'observation z particulières à savoir z = kZ_T avec $Z_T = 2d^2/\lambda$: la distance de Talbot (Figure 1). Le paramètre λ désigne la longueur d'onde avec laquelle l'objet a été éclairé pour créer le champ initial qui se diffracte par la suite lorsque la lumière se propage. L'entier k résulte du fait que si le champ initial se produit une fois à la distance Z_T alors logiquement il doit se reproduire également au bout de la double distance $2Z_T$ et ainsi de suite.

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Abstract

We summarily cover the optical effects of spatial as well as temporal periodical structures. Three effects are considered: spatial Talbot effect, temporal Talbot effect and Lau effect. These phenomena are used in applications in various fields, such as interferometry, photolithography, optical metrology, image processing, 3D imaging. Moreover, the periodic structures have direct applications in the telecommunications world. The Bragg grating presents a a typical exemple of using periodic structures in optical telecommunications. This grating can be a small part of an optical fibre along which the refraction index varies periodically. In addition to spatial structures, periodicity may be temporal. It is, for instance, the case of signal pulse sequences propagating through a monomode fibre. The importance of periodic structure is also emphasized by their possible use for the implementation of other basic periodic structures in telecommunications.

Sommaire

Nous présentons ici un résumé des effets optiques des structures périodiques spatiales et temporelles. Les trois effets présentés ici sont l'effet Talbot spatial, l'effet Talbot temporel et l'effet Lau. Ces phénomènes sont utilisés dans des applications dans des domaines diverses, tels que l'interférométrie, la photolithographie, la métrologie optique, le traitement d'image, l'imagerie 3D, … En outre, les structures périodiques ont des applications directes dans le monde des télécommunications. L'exemple typique est le réseau de Bragg qui est structure spatiale périodique très utilisée en télécommunications optiques. Ce réseau peut être un morceau de fibre optique ayant un indice de réfraction changeant périodiquement le long de ce morceau. Outre les structures spatiales, la périodicité peut être temporelle. C'est le cas d'un signal sous forme d'un train d'impulsion qui se propage à tr avers une fibre monomode. L'intérêt des structures périodique se manifeste également lors de la mise en œuvre d'autres structures périodiques essentielles en télécommunications.
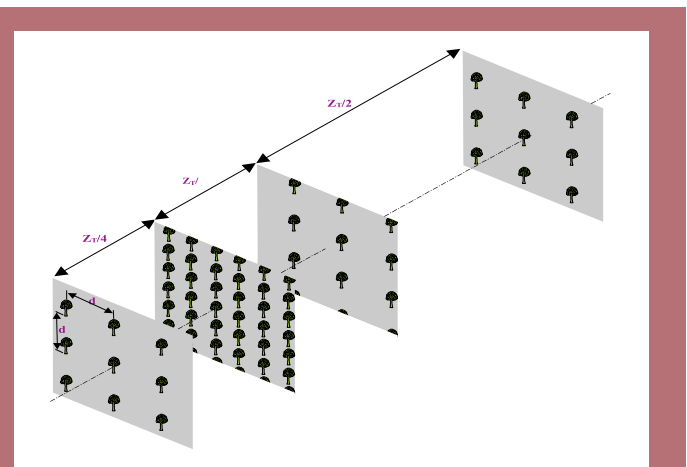
Figure 1 : Effet de la diffraction au niveau des plans de Talbot fractionnaires, $Z_T/4$, $Z_T/2$ et Z_T
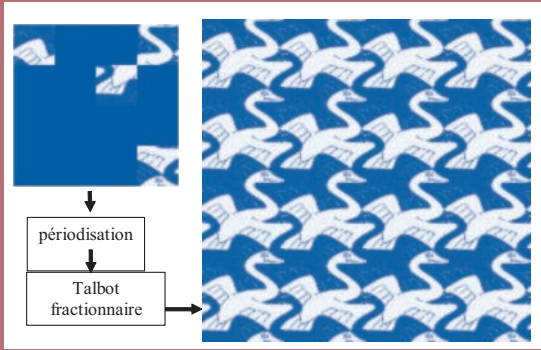
Figure 2: Reconstruction par effet Talbot fractionnaire du tableau artistique d'Escher

2.2 Création de répliques

Si l'on s'intéresse, maintenant, à une fraction (p/q) de cette distance Z_T, on observe, alors, la superposition d'un certain nombre de répliques pondérées et translatées du champ initial qui dépend de la distance d'observation z. On parle dans ce cas de l'effet de Talbot fractionnaire. On conclut qu'aux distances fractionnaires p/q Z_T (q est pair) le signal initial donne naissance à q/2 répliques (pour des valeurs impaires de q, on obtient q répliques) translatées et ayant des poids différents. Ceci nous permet d'obtenir des combinaisons d'images intéressantes formant même des motifs artistiques d'Escher (Figure 2).

A première vue le tableau de la Figure 2 contient des oiseaux de couleur blanche espacés périodiquement. Avec plus d'attention, le lecteur découvrira la présence d'un deuxième champ d'oiseaux de couleur noire. Le tableau d'Escher n'est autre que l'effet spatial du Talbot fractionnaire obtenu par une périodisation du motif de base contenant les différentes parties d'un oiseau.

La Figure 1 montre la distribution du champ diffracté à des différentes distances z de l'axe de propagation. On voit bien qu'après un parcours de Z_T(k=1) et quel que soit le contenu de la période, on retrouve intégralement l'objet de départ.

La situation est identique lorsque la distance parcourue est Z_T/2, cependant on observe un décalage d'une demi-période dans les directions X et Y. À la distance Z_T/4. Non seulement on observe une reproduction intégrale de l'objet initial, mais on assiste aussi à une création de répliques de cet objet décalé d'une demi-période dans les deux directions transversales.

2.3 Création De La Structure Périodique

En pratique, il est souhaitable d'avoir un système basé sur l'effet Talbot qui permet l'utilisation de l'effet Talbot fractionnaire sans besoin de structures périodiques à l'entrée du système. L'essence de la technique, c'est la génération de la périodicité par le système lui-même. Nous avons baptisé cette technique "Imagerie de Talbot" [4]. La périodisation (Figure 2) du motif de base peut être réalisée lors de la mise en œuvre même, par exemple par une réplication au moyen d'un dispositif photographique. Le motif répliqué sera donc l'entrée du système. Une
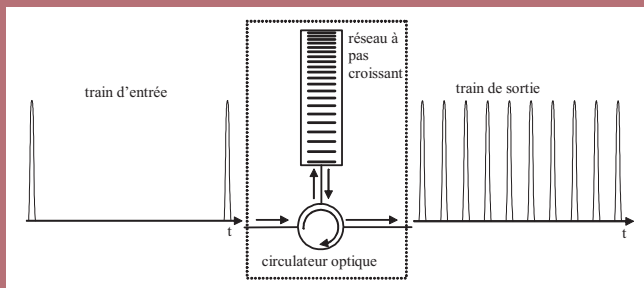
alternative consiste à prévoir un système optique [4] qui fera cette réplication suivie par l'effet Talbot fractionnaire. L'entrée du système sera dans ce cas le motif de base seul (Imagerie de Talbot). Nous avons préparé une animation par Applet pour illustrer cette technique [5]. Le recouvrement et l'inversion du motif, engendrés par l'effet Talbot fractionnaire, sont à l'origine de l'œuvre artistique d'Escher (Figure 2).

L'opération inverse de la périodisation est aussi intéressante, à savoir la concentration de l'information dans une seule période après son passage par le plan Talbot fractionnaire. Dans une récente publication [4], nous avons montré entre autres comment cette technique, appelée "Unification de Talbot", peut être utilisée pour réaliser des faisceaux avec plusieurs géométries (beam shaping).

3.0 Effet Talbot Temporel

Il y a une analogie remarquable entre le comportement optique spatial et temporel des structures périodiques, à l'exception que l'effet spatial agit dans le plan transversal à la propagation de la lumière, alors que l'effet Talbot temporel [2] se manifeste dans la direction longitudinale de la propagation. Du fait de l'existence de la dualité spatio-temporelle, on utilise le même formalisme mathématique pour aborder l'aspect temporel de Talbot en se restreignant à une dimension.

Le Talbot temporel se produit lorsqu'un signal d'impulsions lumineuses courtes et périodiques, produites par un laser, se propage dans un milieu dispersif de premier ordre. On note qu'un milieu dispersif est un milieu dans lequel, les différentes harmoniques, qui composent l'impulsion se propagent avec des vitesses différentes, entraînant ainsi l'élargissement de l'impulsion au cours de sa propagation. La largeur temporelle et la forme de l'impulsion correspondent à la largeur et la forme des motifs contenus dans l'exemple de la diapositive cité dans le cas spatial. Le temps de répétition joue le rôle de la période spatiale.

Au fur et à mesure qu'une impulsion périodisée se propage dans un milieu dispersif, elle subit un élargissement temporel aux niveaux des ses ails. About d'une certaine distance de parcours du signal chaque impulsion chevauche avec les deux impulsions des périodes voisines. De ce fait, l'information véhiculée par le signal périodique est affectée. Le chevauchement des impulsions élargies est constructif dans certaines régions et destructifs dans d'autres de sorte que des nouvelles impulsions, de même forme que les impulsions initiales, se forment. Il en résulte que la période contient des impulsions supplémentaires et par conséquent la fréquence des impulsions est doublée, triplée et d'une façon générale répliquée n fois. On parle dans cas de l'effet Talbot temporel fractionnaire [2].

L'intérêt de ce phénomène se manifeste au niveau d'utilisation de la fibre comme un milieu dispersif de premier ordre [2]. Pour se faire, on introduit dans la fibre des modifications de son profil d'indice de réfraction. En effet pour créer la dispersion de premier ordre, on rend l'indice du cœur de la fibre, initialement uniforme tout le long de la fibre, variable d'une façon binaire et quasi-périodique avec une période longitudinalement croissante. Cette structure est connue sous le terme de réseau de fibre optique à pas linéairement croissant (Linearly Chirped Fiber Grating). Cette technique permet de maintenir exactement la forme du signal d'entrée à la sortie de la fibre ayant une longueur précise. Elle permet également de générer des taux de répétition d'impulsions variables atteignant la gamme de Terahertz [6, 7] (Figure 3). Ceci est d'un grand intérêt dans le domaine des télécommunications à haut débit. Tel que la Figure 3 le montre, le train d'impulsions d'entrée traverse le circulateur optique qui le dirige vers le réseau à pas linéairement croissant. Le signal subira des réflexions consécutives par les surfaces de transition dans le réseau. Du fait de ces réflexions et étant donné que l'intervalle de séparation des transitions est variable, les impulsions du train seront répliquées et décalées, ce qui donne un train de sortie plus dense (Figure 3).

4.0 Effet Lau

Lorsque la cohérence spatiale manque, l'effet Talbot n'est plus valable et on observe plutôt un deuxième effet, découvert par E. Lau en 1948. L'idée de Lau repose sur la sélection périodique des points de la source incohérente étendue (Figure 4). Cette sélection doit se faire au niveau de deux plans successifs séparés par une distance particulière, à savoir le quart de la distance de Talbot. Nous avons préparé une animation par Applet qui présente de principe [8].

Le montage de Talbot ressemble au montage de Lau. À la place de la source de lumière ponctuelle monochromatique, Lau utilise une source
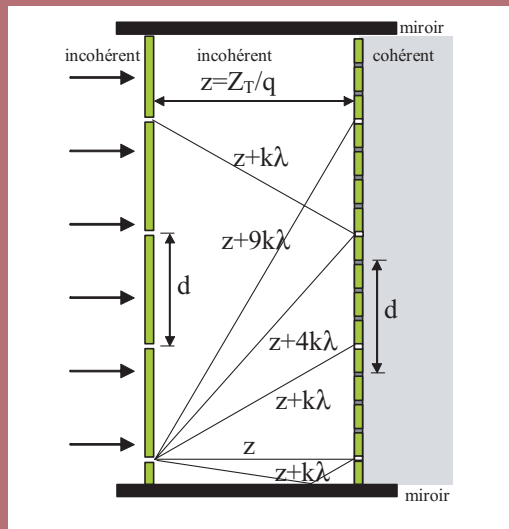

Figure 3: Générer de taux de répétition d'impulsions variables atteignant la gamme de Terahertz

Figure 4: Création de la cohérence spatiale: Montage classique de Lau + Ajout d'ouvertures + Ajout de miroirs longitudinaux

étendue. Son montage consiste à éclairer au moyen d'une source monochromatique de longueur incohérente et étendue, un premier réseau d'amplitude d'ouvertures relativement petites comparées à la période (Figure 4 sans miroirs et sans ouvertures grises). Ainsi, on crée une matrice de sources ponctuelles incohérentes entre elles et espacées d'un pas de d. Au bout d'une distance, qui correspond au quart de la distance de Talbot, $z = Z_T/4 = d^2/2$, on place un deuxième réseau d'amplitude de même période d. À la sortie de ce dernier, on obtient un ensemble de points spécialement cohérents entre eux. Pour illustrer ce principe, considérons une ouverture quelconque n du réseau de sortie et examinons les rayons qui sortent à travers elle. Ces rayons doivent obligatoirement provenir des ouvertures du premier réseau. Le fait que nous imposons une distance de séparation $z=Z_T/4$ entre les deux réseaux fait que tous les rayons, sortant de l'ouverture n, parcourent la même distance à un multiple de la longueur d'onde près. Par conséquent, les sorties des ouvertures du deuxième sont optiquement identiques. En d'autres termes, indépendamment du profil de phase du front d'onde à la sortie du premier réseau, la phase (et même l'amplitude) sera la même au niveau de toutes les ouvertures du deuxième réseau, d'où la cohérence spatiale mutuelle.

Nous avons généralisé le montage de Lau ($Z_T/4$) en prévoyant une distance fractionnaire $z=Z_T/q$ (q multiple de 4). En effet cette condition, implique que les chemins optiques des rayons, traversant les deux réseaux, diffèrent d'un multiple de la longueur d'onde (Figure 4).

Toutefois, un problème majeur surgit du fait de l'utilisation de deux réseaux bloquant presque la totalité de la lumière. Pour y remédier, nous avons proposé des solutions, basées surtout sur la diffraction des réseaux d'amplitude. Nos solutions sont de nature à ouvrir les perspectives vers toutes les applications de l'effet Talbot spatial. De plus, nous avons proposé une solution diffractive permettant de générer la cohérence pour les Lasers à cavité verticale (VCSELs) qui sont de plus en plus utilisés surtout en télécommunications. Ces lasers ont l'avantage d'être miniaturisés et contrôlables séparément. Toutefois pour beaucoup d'applications et surtout en télécommunications, ils nécessitent d'être mutuellement cohérents.

Pour réduire les pertes énergétiques dues au premier montage classique de Lau, notre première solution consiste à augmenter la densité des sorties en prévoyant des ouvertures régulièrement espacées dans chaque période (ouvertures grises sur la Figure 4). Du fait que l'espacement entre deux ouvertures voisines est 2d/q, un rayon quelconque traversant les deux réseaux parcourt un chemin optique z+k, d'où la cohérence spatiale mutuelle.

Notre deuxième solution pour améliorer le bilan énergétique du système classique de Lau consiste à utiliser des miroirs longitudinaux (Figure 4). Certains rayons initialement perdus (dans le montage initial de Lau) seront réorientés vers le deuxième réseau. Ceci nous permet de transformer des sources incohérentes, qui sont généralement facilement réalisable à coût réduit, en des sources cohérentes.

5.0 Conclusion

Cet article a donné un aperçu sur les structures optiques périodiques et leurs applications dans divers domaine particulièrement en télécommunication. Le principe de base étant le même, on distingue deux structures optiques: spatiale et temporelle combinant deux effets Talbot et Lau. Notre approche simplifiée peut servir comme un outil dans la compréhension des phénomènes relevant de la physique quantique, tel que l'exemple du paquet d'onde quantique représentant un électron dans un atome.

6.0 Remerciements

7.0 Références

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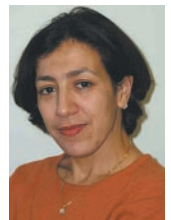
Habib Hamam a obtenu un B.Ing. et une M.Sc. en traitement de l'information de l'Université Technique de Munich, Allemagne 1988 et 1992, et un Ph.D en télécommunications de l'Université de Rennes I conjointement avec l'École Nationale Supérieure de Bretagne, France 1995. Actuellement, il occupe le poste de professeur agrégé au département de génie électrique de l'Université de Moncton. Dans ses recherches scientifiques, il s'intéresse aux télécommunications optiques, à la diffraction, aux composants de fibres optiques, à l'optique de l'oeil, au génie biomédical et à l'apprentissage par réseaux électronique (E-Learning).
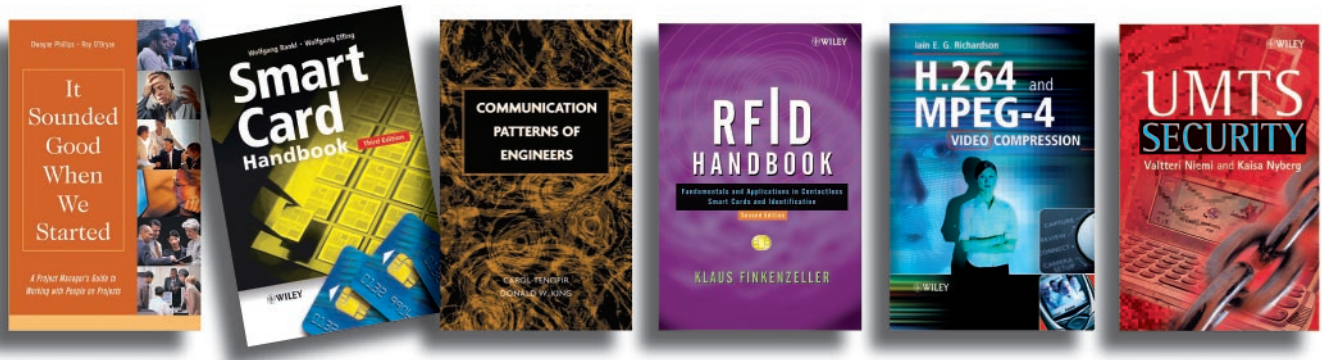
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