Real-World Experience with a Mobile Broadband Network

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September 23, 2004

IEEE Communications Society

Oakland-East Bay Chapter, CA

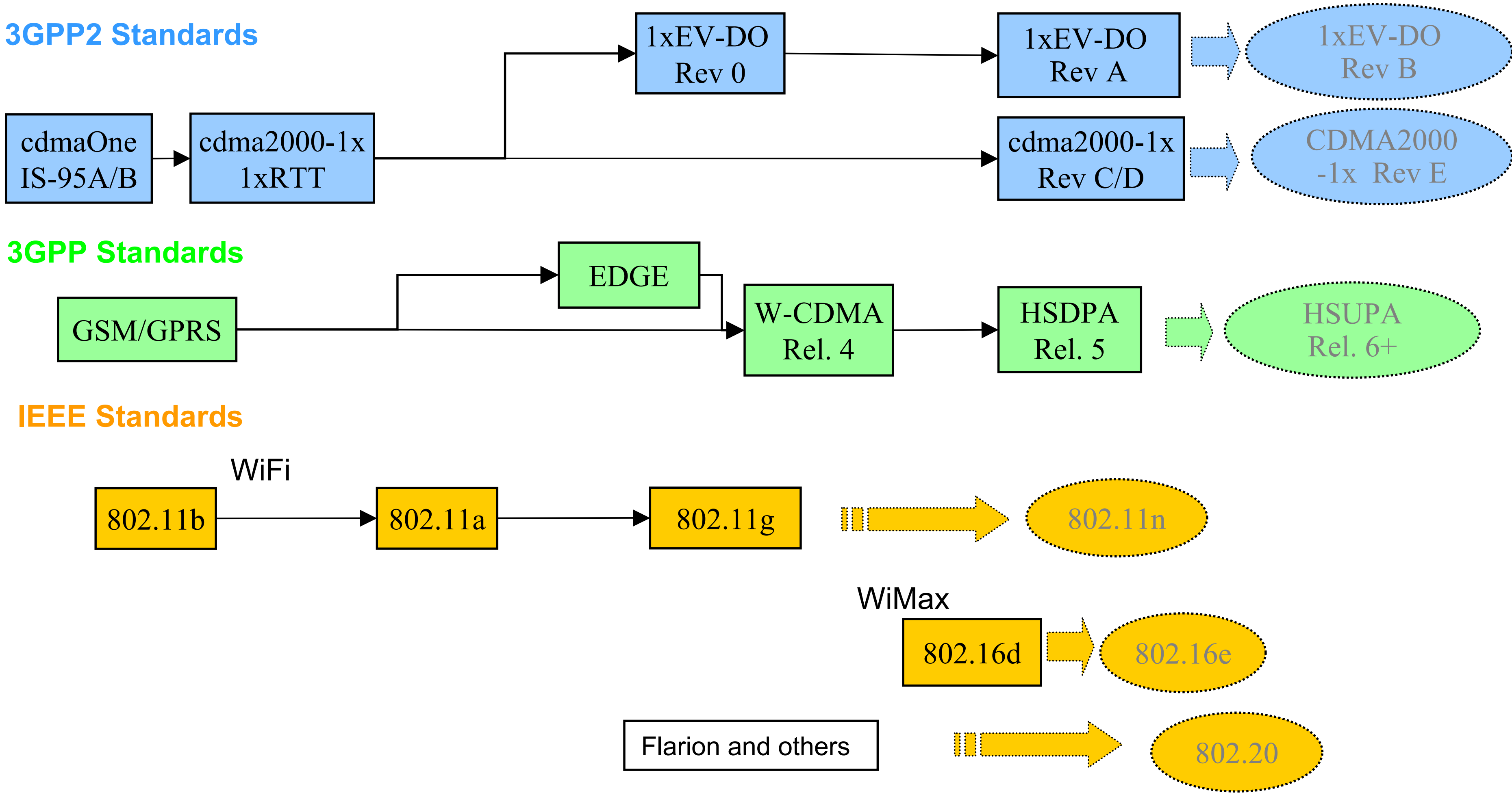
Outline

- Introduction
- Overview of 1xEV-DO Network
- Performance of Scheduler
- Performance of Hybrid ARQ
- An Integrated cdma2000-1x and 1xEV-DO Network
- Conclusions

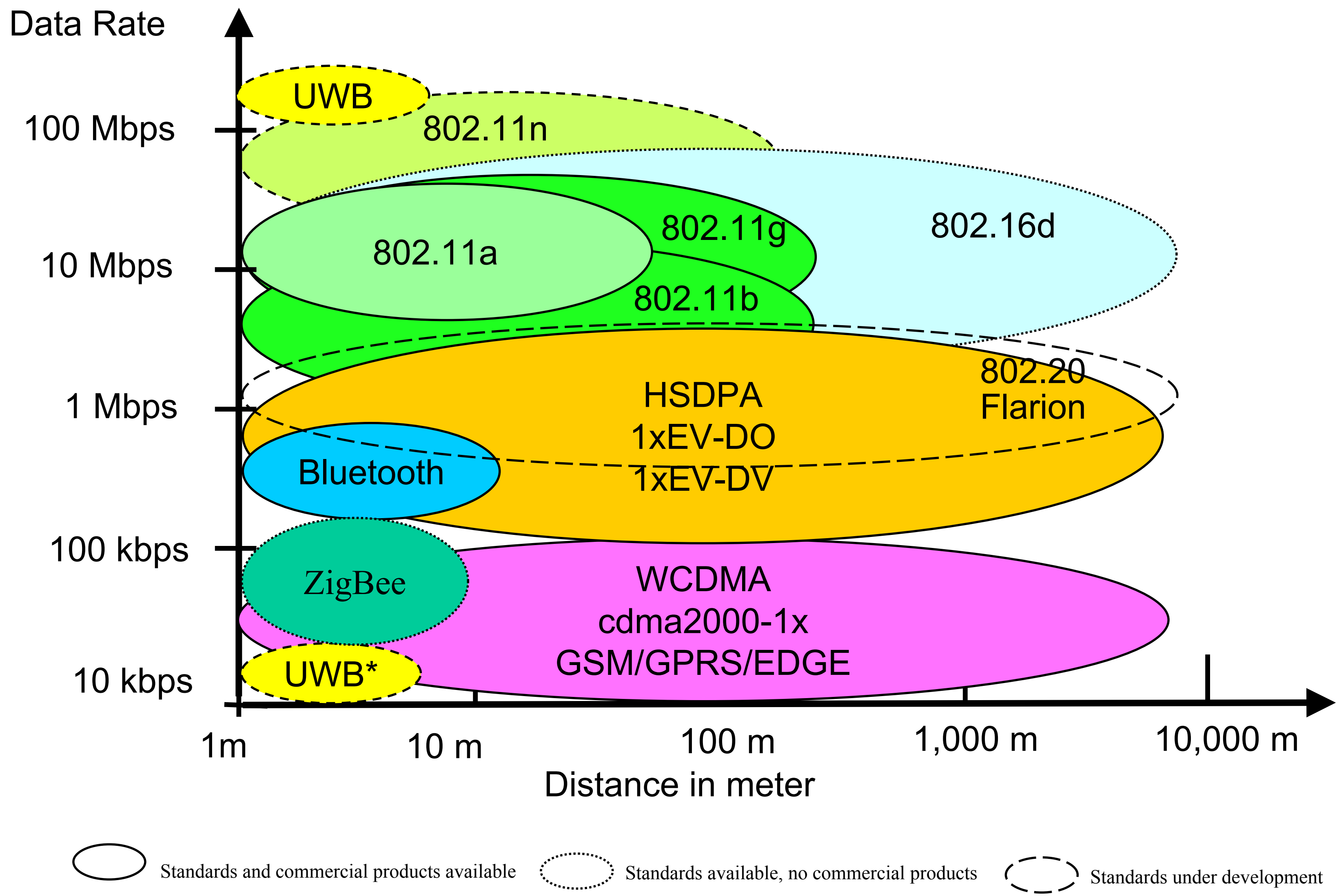
Introduction

- Applications drive architecture
  - Traditional wireless network: voice centric
    - Low data rate
    - Low latency
    - Equal and stringent service quality
  - Evolutional wireless network: versatile applications beyond voice
    - Very high data rate
    - Flexible latency
    - Flexible service quality
- Mobile wireless data network is evolving to support broadband services
  - Large file transfer
  - Intranet and Internet
  - Multimedia

Wireless Broadband Technologies



Data Rate vs. Coverage Distance



TIA/EIA IS-856 1xEV-DO

- 1xEV-DO is an integral part of the cdma2000 family of standards developed by 3GPP2, and approved by ITU as IMT-2000 system for 3G to address MOBILE broadband access
  - Peak rate 2457.8 kbps on forward link for 1xEV-DO Rev 0
    - 1xEV-DO Rev A supports peak rate 3072 kbps on forward link, 1843.2 kbps on reverse link
  - Forward link throughput increased by
    - Full power transmission
    - Adaptive modulation and coding (AMC)
    - Hybrid Automatic Repeat reQuest (H-ARQ)
    - More efficient scheduling and multiple user diversity
  - IP based packet data architecture

Overview of 1xEV-DO: AMC

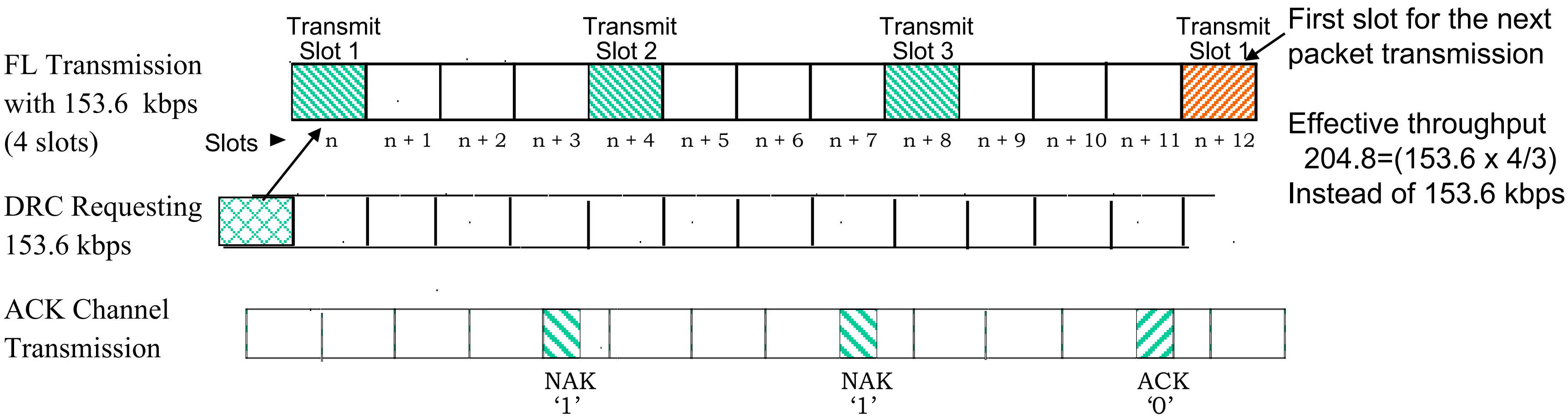
- Adaptive server selection, Adaptive Modulation and Coding (AMC)
  - The best server, modulation and coding schemes are adaptive to the channel carrier-to-interference ratio (CIR) based on feedback from reverse link Data Rate Control (DRC) channel at 600 Hz rate

Physical Layer Data Rate (kbps)	Modulation	Code Rate	Slots per Packet
38.4	QPSK	1/5	16
76.8	QPSK	1/5	8
153.6	QPSK	1/5	4
307.2	QPSK	1/5	2
307.2	QPSK	1/3	4
614.4	QPSK	1/3	1
614.4	QPSK	1/3	2
921.6	8PSK	1/3	2
1228.8	QPSK	1/3	1
1228.8	16QAM	1/3	2
1843.2	8PSK	1/3	1
2457.6	16QAM	1/3	1

Overview of 1xEV-DO: Scheduler and H-ARQ

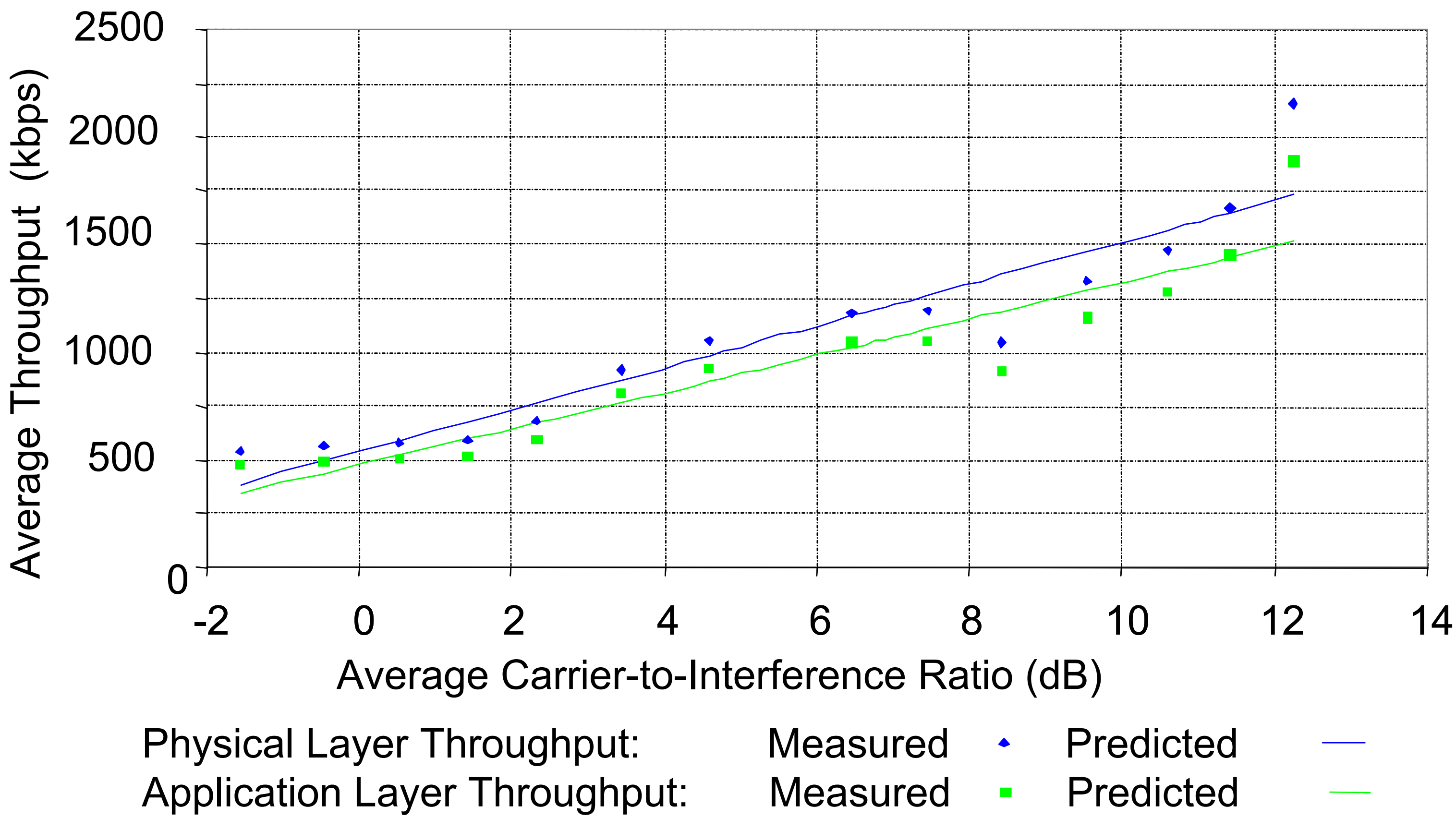
- Fast Scheduler
  - Fast scheduler takes into account a-priori channel state information from DRC
  - Users are served when experiencing better than average channel Carrier-to-Interference Ratio (CIR)
  - Aggregated sector throughput increases as number of users increases due to scheduler taking advantage of multi-path fading diversity from users

- Hybrid ARQ
  - Earlier termination (an ACKnowledgment received earlier) will increase the effective throughput



Overview of 1xEV-DO: Phy & App Throughput

- The average physical and application layer throughput for ftp transmission over a trial network

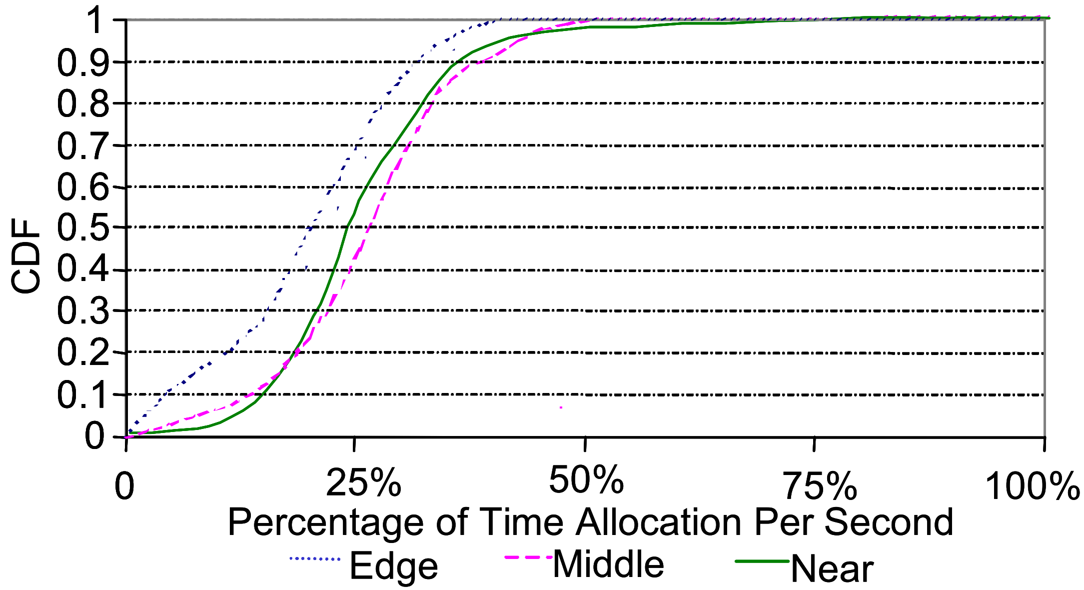


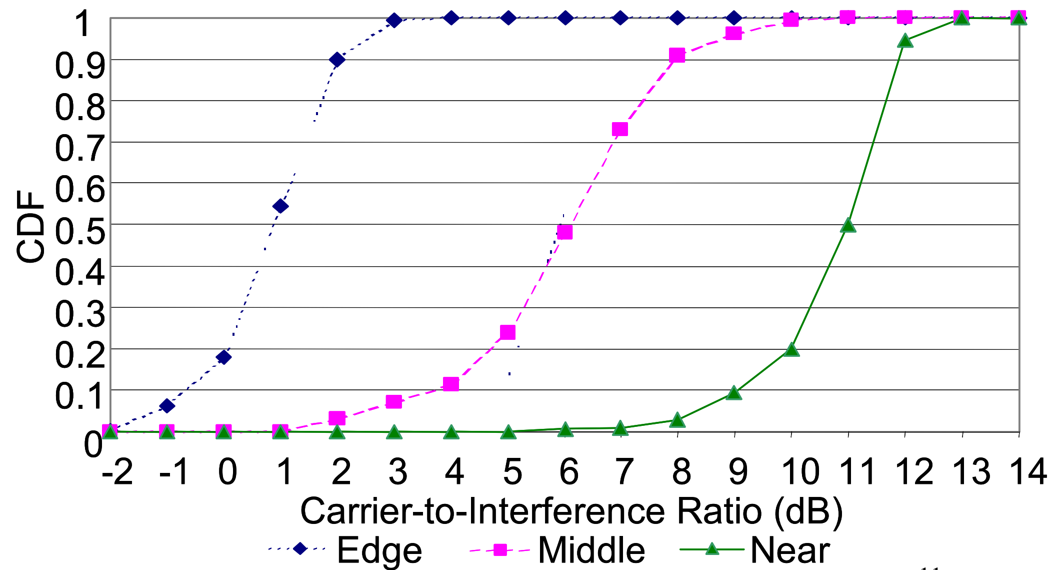
Scheduler

- Scheduler determines slot assignment for each user
  - Advanced scheduling scheme improves the spectrum efficiency
- Proportional fairness algorithm
  - Scheduling based on channel condition, time allocation history and user data on the pipe
  - Serving the user at better than average channel conditions and achieving multiple user diversity gain
  - User throughput optimized to the maximum achieve level regardless of other user RF conditions
- Fairness versus throughput efficiency tradeoff
  - Gives higher priority and longer time allocation to good RF condition could increase aggregated sector throughput at the cost of poor RF condition user
  - Absolutely equal throughput for all users will sacrifice network efficiency
- Scheduler based on class of service requirement
  - Higher priority on time allocation can be used to differentiate services, support delay-sensitive or rate-sensitive applications

Scheduler: Time Allocation Per User

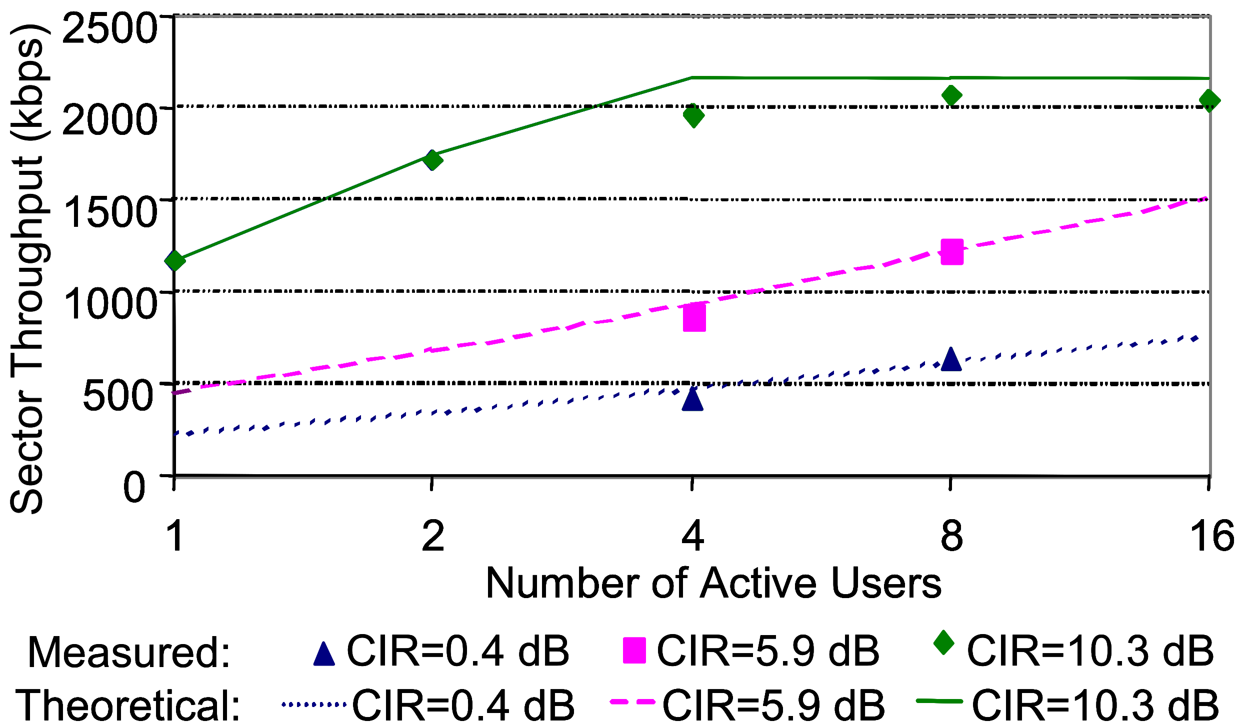
- The proportional fairness scheduler provides fair chance for every user who needs to transmit data
  - Users under poor, average and good RF conditions share similar CDF of time allocations
  - The average percentage of time allocation for each user is around 25% when 4 users are active in the system
  - The good RF condition user in a mixed RF scenario did not dominate radio resources on time basis





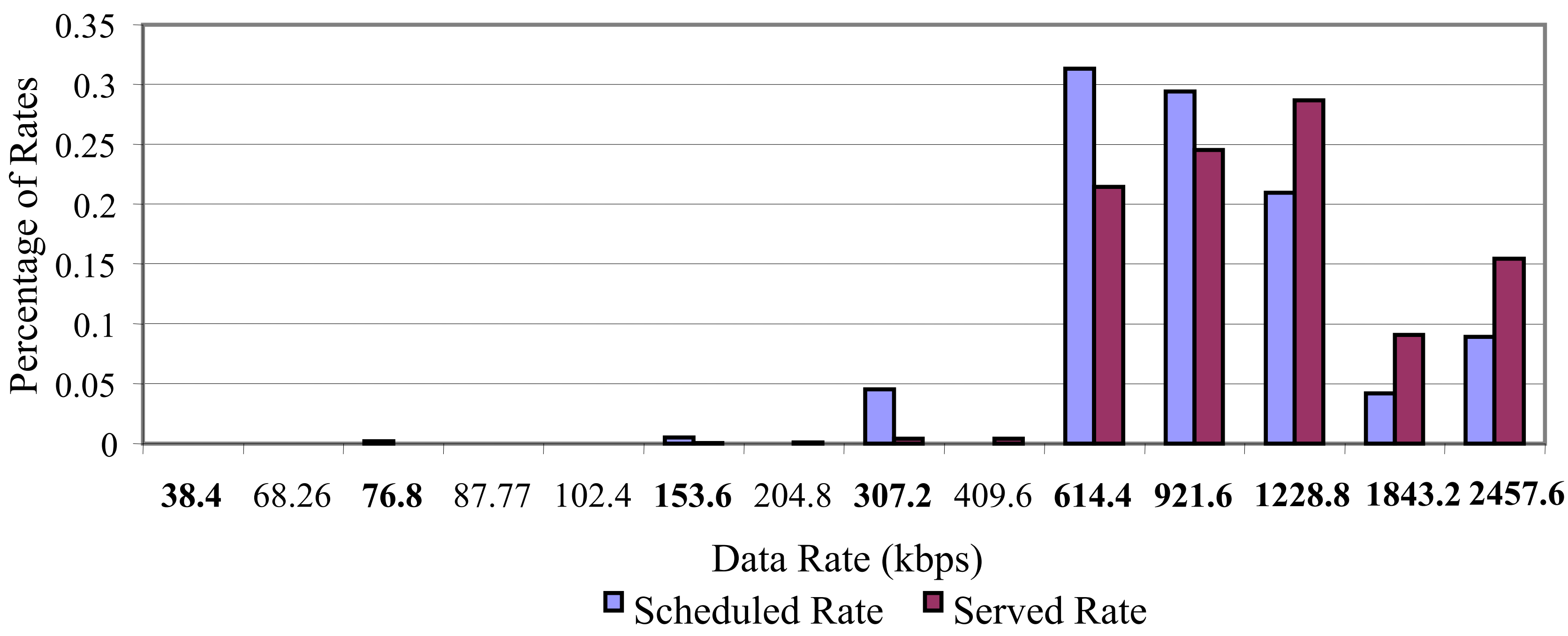
Scheduler: Throughput Performance

- The sector throughput increases as number of users increases. The user throughput increases as the radio condition improves
  - The multiple users gain is particularly strong under poor RF conditions
  - Aggregated throughput of 4 and 16 users could increase to 2 and 3.4 times that of a single user throughput, respectively
  - The throughput will be saturated as the number of users increases to more than 4 under good RF conditions



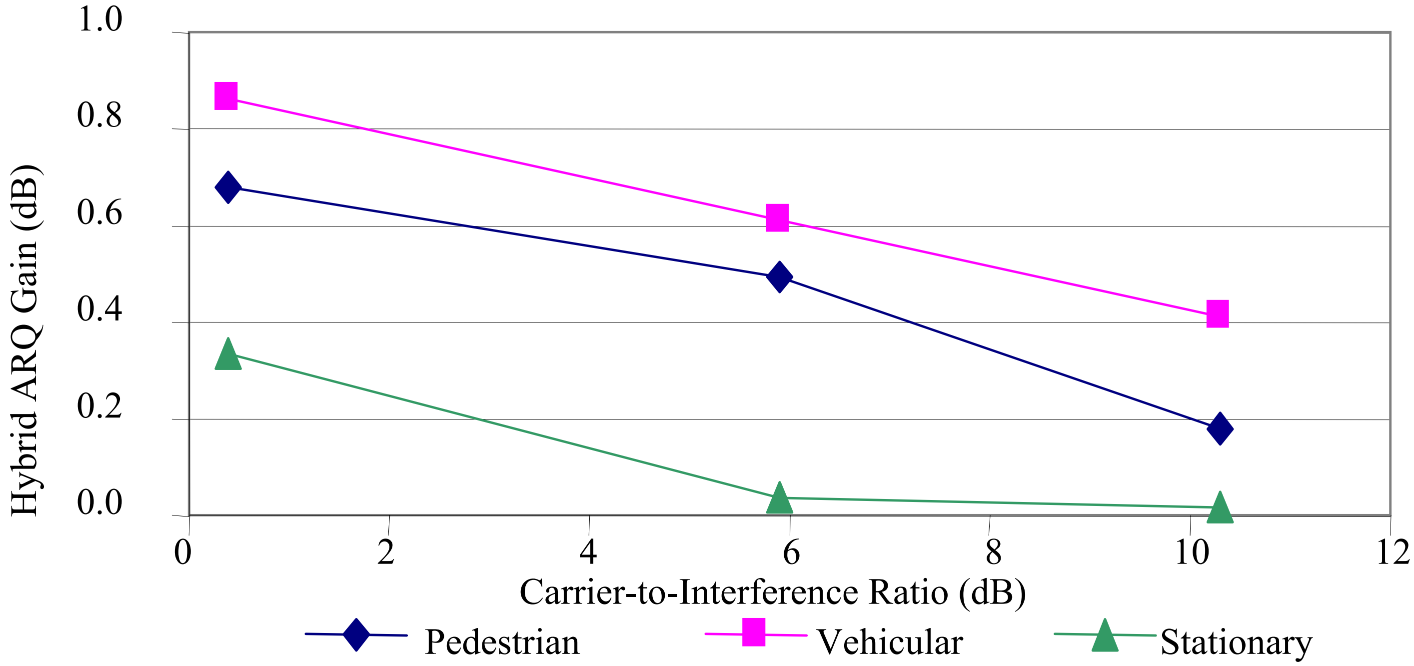
Hybrid ARQ

- Hybrid ARQ provides further control mechanism to improve the data rate under adverse radio conditions
  - Hybrid ARQ enables early-termination of multi-slot transmission on physical layer and increases the user data rate.
- The chart illustrates the scheduled and final served data rate for a user moving at the edge of a sector
  - Hybrid ARQ results in a new set of derived packet types with increased rate



Hybrid ARQ: Throughput Gain

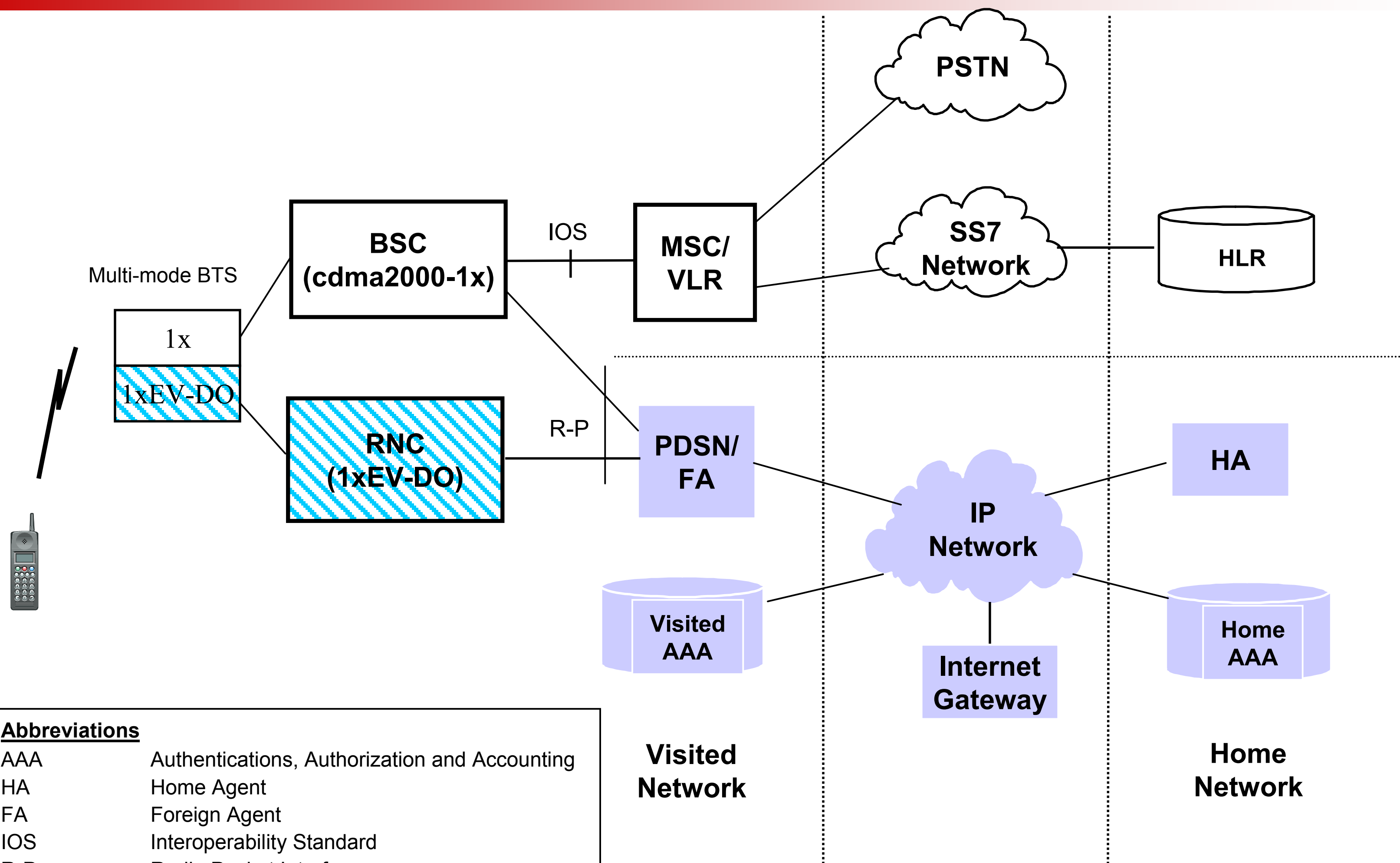
- Hrbrid ARQ supports up to 1 dB throughput gain across network
  - The hybrid ARQ gain is significantly higher when mobile is at edge of the cell with vehicular speed, where a-priori channel estimate is not accurate due to highly unpredictable channel conditions and interference patterns
  - The gain is minimal when the user is near the cell with good a-priori channel state information
- Hybrid ARQ combined with AMC and scheduler results in high average sector throughput across various RF environments



An Integrated Network Solution

- 1xEV-DO is an integral part of the cdma2000 family of standards
  - The same 1.2288 MHz frequency bandwidth
  - The similar reverse link budget enables one-to-one overlay of 1xEV-DO on existing cdma2000-1x network
  - Hybrid mode supports smooth seamless hand-off between 1xEV-DO and cdma2000-1x
    - cdma2000-1x voice calls are successfully terminated and originated during 1xEV-DO active data session using the trial network
- A highly integrated network architecture provides a spectrum efficient way for both delay sensitive voice and delay tolerant data services
  - The integrated network can share packet data network elements, such as Packet Data Serving Node (PDSN), Foreign Agent (FA), Authentications, Authorization and Accounting (AAA), and Home Agent (HA)
  - Only Radio Network Controller (RNC) and dedicated 1xEV-DO base station modem cards are needed to upgrade the existing cdma2000-1x network

An Integrated Network: Architecture



Abbreviations	
AAA	Authentications, Authorization and Accounting
HA	Home Agent
FA	Foreign Agent
IOS	Interoperability Standard
R-P	Radio Packet Interface
RNC	Radio Network Controller
PDSN	Packet Data Serving Node

New network elements required for 1xEV-DO

Shared network elements with cdma2000-1x

An Integrated Network: Link Budgets

- Reverse link budgets for 1xEV-DO and cdma2000-1x
  - The link budget of a 1xEV-DO system is similar to that of cdma2000-1x under serving rate of 38.4 kbps

	cdma2000-1x	1xEV-DO
Data Rate (kbps)	38.4	38.4
Portable Tx ERP Power (dBm)	23	23
Base Rx Antenna Gain (dB)	17	17
Base Rx Cable Loss (dB)	3	3
Receiver Sensitivity (dBm)	-120.64	-120.80
Thermal Noise (dBm/Hz)	-169.98	-169.98
Noise Figure (dB)	4	4
Data Rate (dB-Hz)	45.84	45.84
Eb/No Req. @ PER 3% (dB)	3.5	3.34
Total Link Margin (dB)	25.17	25.17
System Loading (75%) (dB)	6.02	6.02
Log-normal Std. Dev. (dB)	8.00	8.00
Fading Allowance (dB)	10.25	10.25
Soft Hand-off Gain (dB)	4.1	4.1
Body Loss (dB)	3	3
Building/Vehicle Penetration Loss(dB)	10	10
Maximum Path Loss (dB)	*132.46*	*132.62*

Conclusions

- The 1xEV-DO has achieved high data throughput and high spectral efficiency through a combination of adaptive modulation and coding, fast scheduler and hybrid ARQ
- The aggregated sector throughputs increases as the number of users increases
- The proportional fairness scheduler provides fair chance for each user to share radio resources in a timely manner with an efficient network throughput
- An integrated 1xEV-DO and cdma2000-1x network can support both delay sensitive voice and delay tolerant data services