Future Internet Architecture: From Network Virtualization to Clean-slate Post-IP

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Agenda

- Motivation: why FIA?
- Network Virtualization
- Post-IP Future Internet Architecture
- Converged Network & Service Test-bed
- Q&A

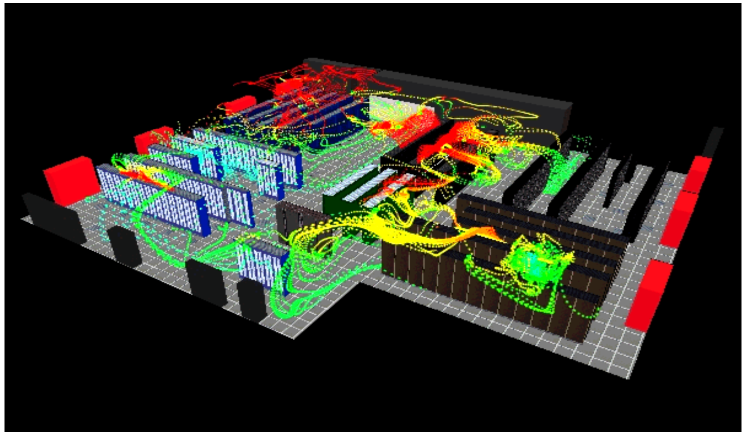
Challenges faced by Current Internet

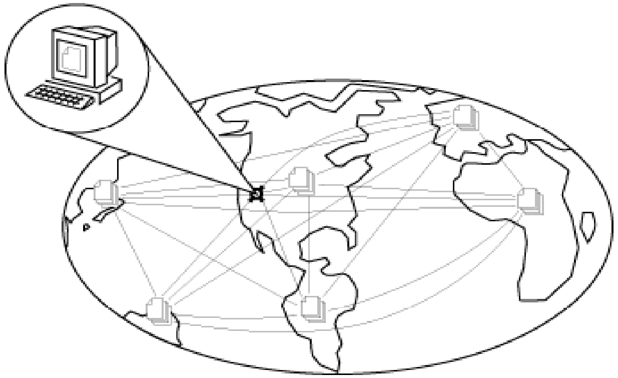
IoM (Internet of Media), IoT (Internet of Things), IoS (Internet of Services) have pushed Internet to its limit in terms of:

- Performance:
  - 0.5Million backbone routers, 9M BGP routes, 1T webpage items on Google, 15hours video content added into video websites per minute, … 60% increase in Internet traffic flow p.a.
  - Furthermore, IoT makes billions and trillions of “things” connected into the Internet!
  - The Internet becomes huge and more complex.
- Security:
  - e.g., 90M visa card users hacked in Europe and North America at 2007;
  - DNS server of Storm (Video) Co. being attacked at 2009, leading to 15 provinces’ network malfunction in China.

Challenges faced by Current Internet

- Energy Consumption:
  - ICT energy consumption in 2007 in China equals to the energy generated by Three-Gorge Power Station
  - 1 Google search = 11W bulb for 1 hour
  - Green!
- Network Management:
  - Becoming more difficult and almost unmanageable.
  - including content management (e.g., piracy)





Path to Future Internet: Dirty Slate

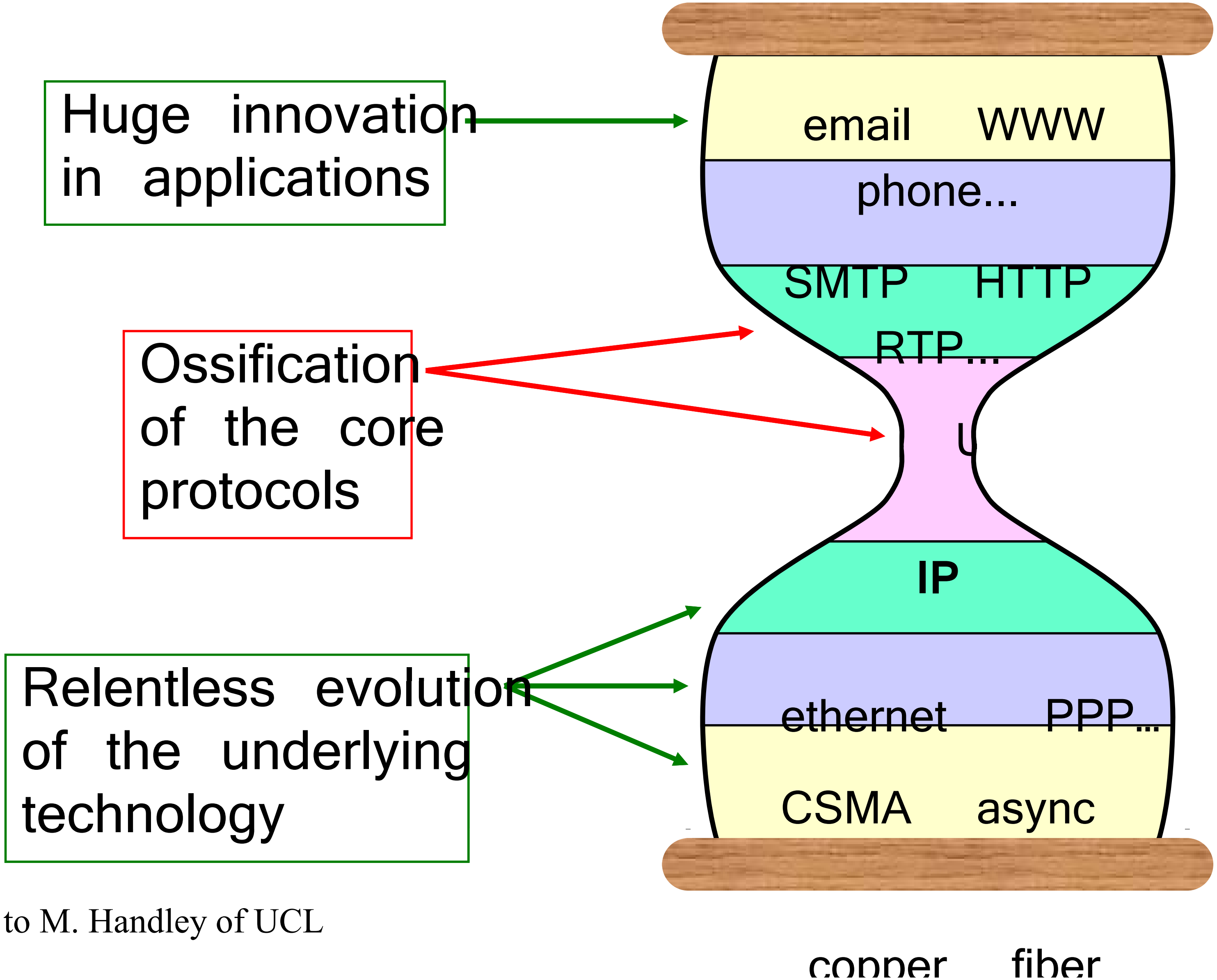
- Solutions: back-compatible, evolutionary, incremental
  - Quality of Service problem? Then IntServ/DiffServ
  - More efficient routing? -> MPLS (Multi-Protocol Label Switching)
  - Security problem? Then IP VPN: Virtual Private Network
  - Not enough IP addresses? Then IPv6.
  - Mobility problem? Then Mobile IP or MIPv6
- Initiatives:
  - NGI, Internet2 at US, Ambient Network in EU,
  - APAN in Japan, CNGI in China.
- Problems:
  - Adding patches and making the Internet more complex and thus more difficult to achieve global optimization.
  - Limiting the further development of the Internet.

Path to Future Internet: Clean-slate

- Revolutionary (bold!)
- Do endpoints really matter? Or is it the information that is more important?
  - IP may be "the" problem!

- Endpoint-centric services move towards information retrieval through, e.g., CDNs (Content Distribution Networks), youTube, Twitter
  - But how about at the network layer?

Ossification of IP-based Infrastructure

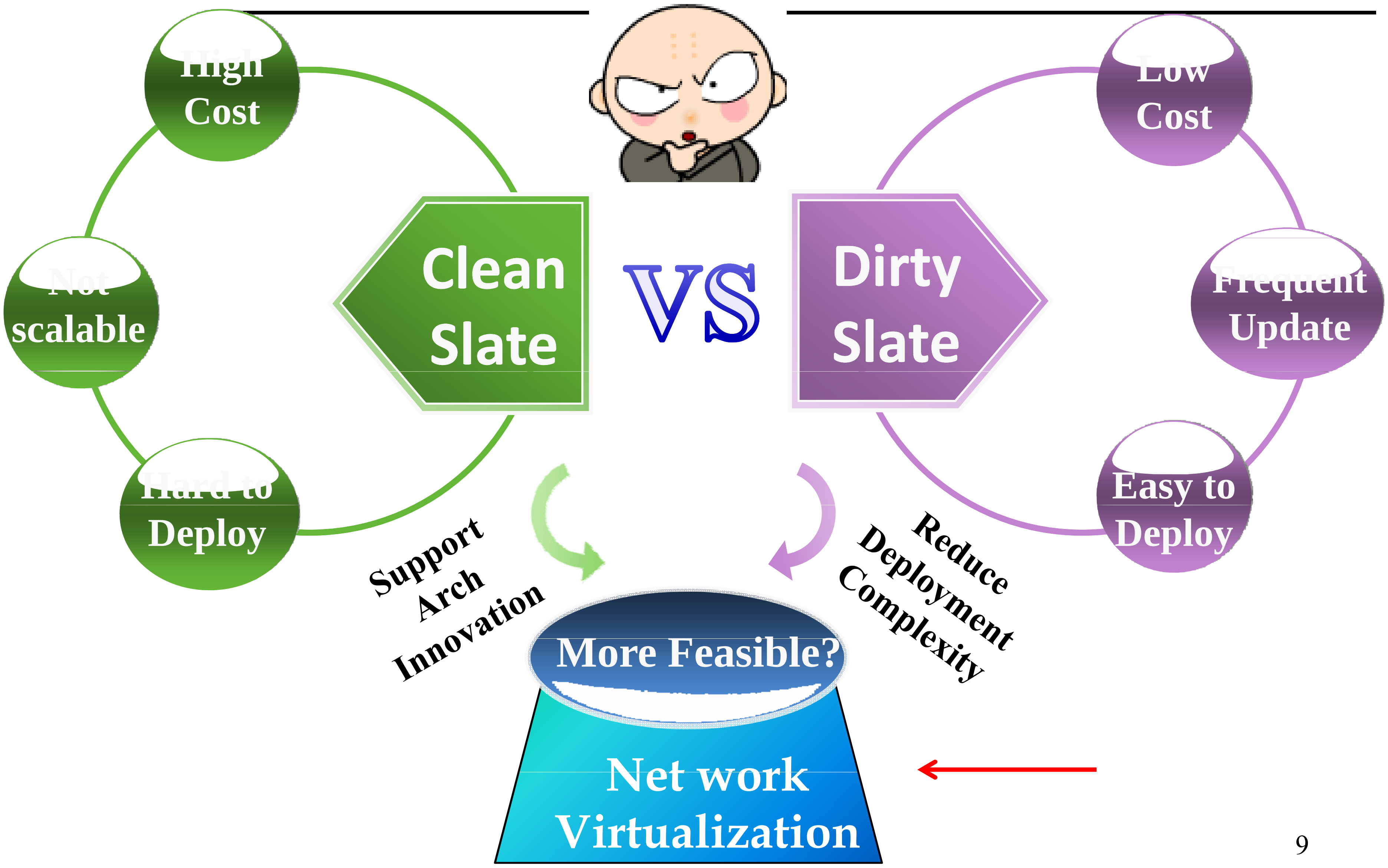


Courtesy to M. Handley of UCL

Observations

- The current Internet is end point centric which has contributed to a number of its problems, such as
  - SPAM, virus, denial-of-service attacks,
  - poor support for **mobility** and multimedia content distribution.
- The current Internet is in favour of senders and receivers passively receive.
  - Economically, receivers are forced to carry the cost of unwanted traffic
- Google youTube's content distribution networks get bigger and more expensive (also for ISPs).
- There is a consensus that a fundamental reform of the Internet is inevitable in the near future.

What is the Way Out?



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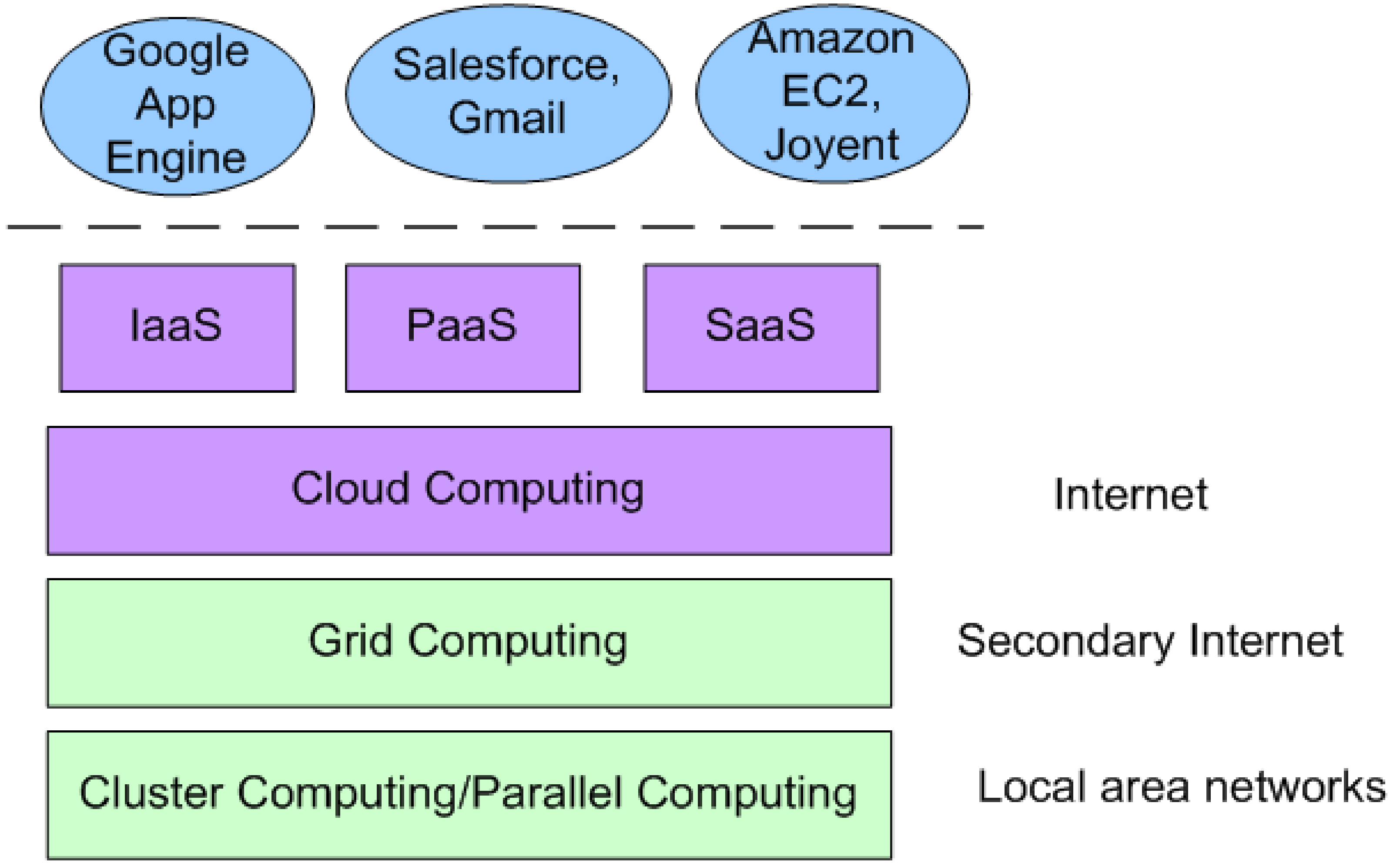
IT Resource Virtualization - Cloud computing



IaaS: Infrastructure as a Service, e.g., XCP

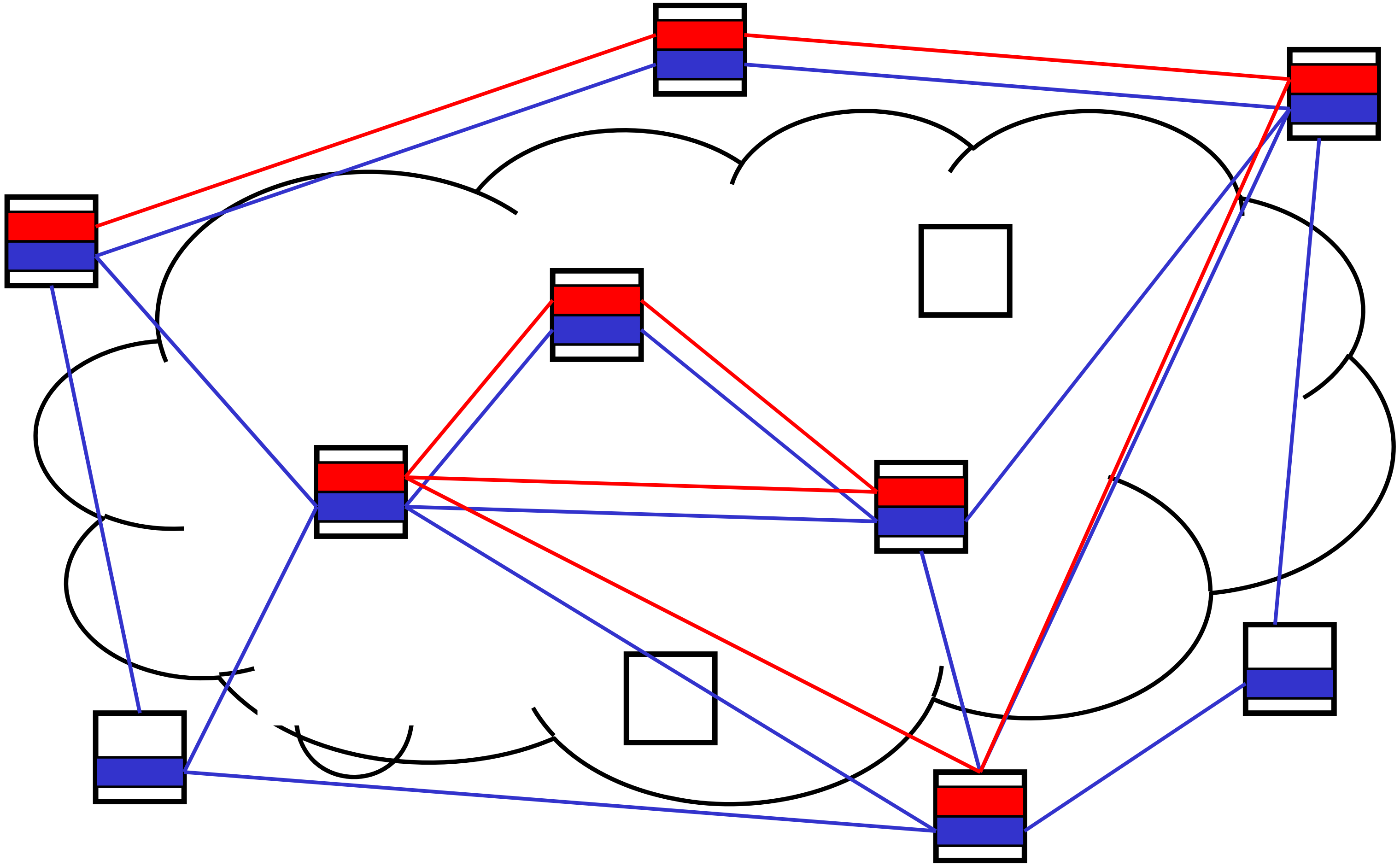
PaaS: Platform as a Service, e.g., VMware

SaaS: Software as a Service, e.g., SPOON

Network Virtualization

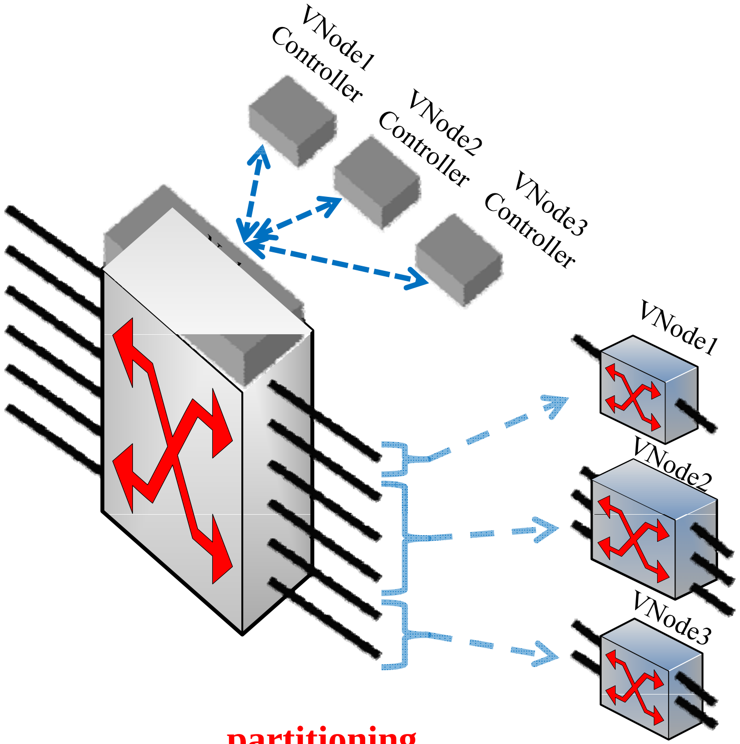
- Network Virtualization is the logical next step after cloud computing .
- Network virtualization provides an **abstraction** layer that decouples physical network devices from business services delivered over the network to create a more agile and efficient infrastructure.
- It allows multiple applications to run side-by-side over the same physical network.
  - Each virtual network has *its own business or service oriented policies* while providing the security, availability and performance required for each service.
- Virtual networks optimize the manageability and control of physical networks that are shared between multiple applications.
  - Thus resulting in a quickly deployable, more reliable service.
- **Enable Agile Business:** Accelerate the roll-out of new services and advanced capabilities through automated multi-vendor provisioning.

Slicing

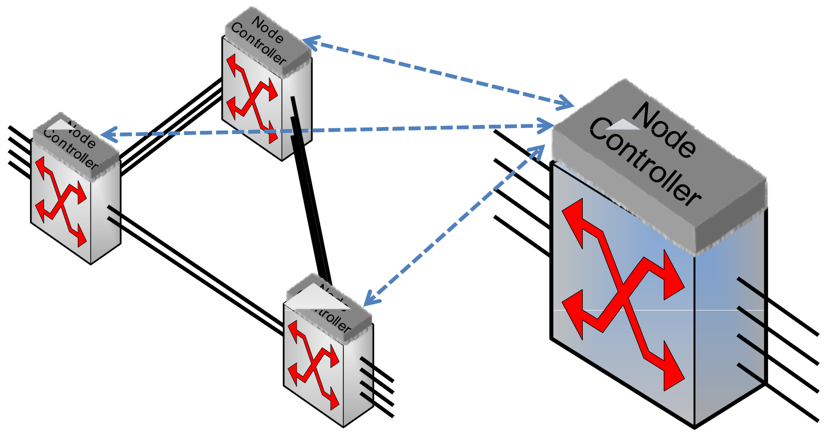


Node Virtualization

- **Virtual node** is the virtual version representing the partition of a single physical node or the aggregation of multiple physical nodes (e.g. L3 router, L2 switch or L1/L0 optical cross connects - OXC).



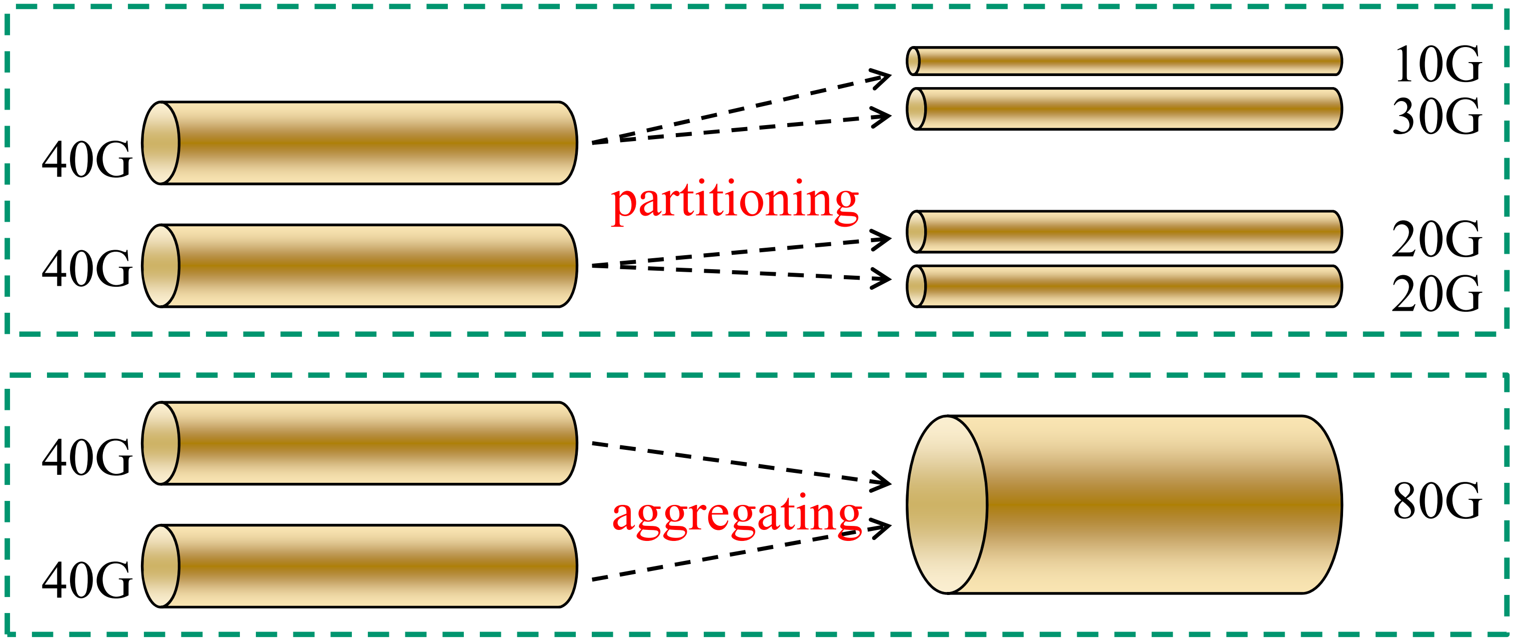
partitioning



aggregating

Link Virtualization

- **Virtual link** is a connection (e.g. a cable between a pair of routers, optical light path, wavelength, sub-wavelength) between one port of a virtual network element to a port of another virtual network element.

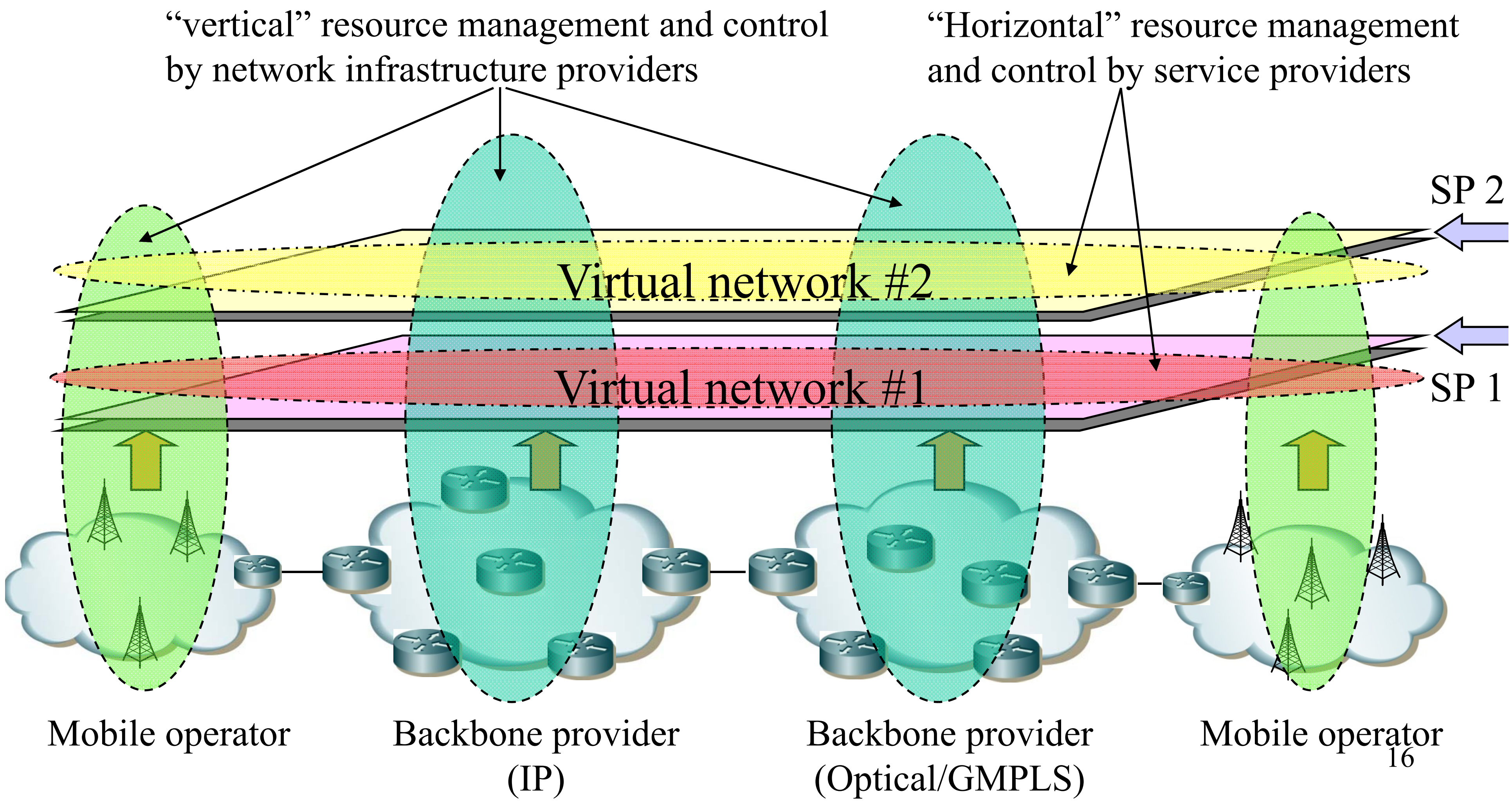


Wavelength with fixed bandwidth

Virtual link with variable bandwidth

Virtual Resource Management: EU FP7 EVANS Project

- End-to-end Virtual Resource Management across Heterogeneous Networks and Services (EVANS)

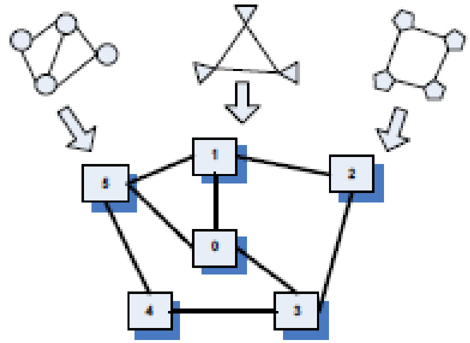


NV Issues in Wired Networks

- Mapping and Embedding: static vs. dynamic
- Resource allocation & Scheduling
- Energy Efficiency: putting some nodes or links into sleep mode

Mapping or Embedding – Offline, Static

- One-off mapping done offline,
- e.g., Zhu and Ammar. "Algorithms for Assigning Substrate Network Resources to Virtual Network Components", Infocom'06

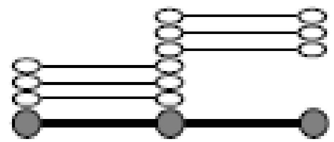


- Objective: to achieve load balancing in terms of stress across either:
  - Node:

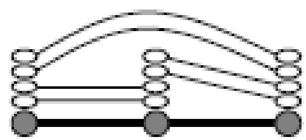
$$R_N(t) = \frac{\max_{v \in V_S} S_N(t, v)}{\left[\sum_{v \in V_S} S_N(t, v)\right] / |V_S|}$$

  - Link:

$$R_L(t) = \frac{\max_{e \in E_S} S_L(t, e)}{\left[\sum_{e \in E_S} S_L(t, e)\right] / |E_S|}$$



Optimal link stress

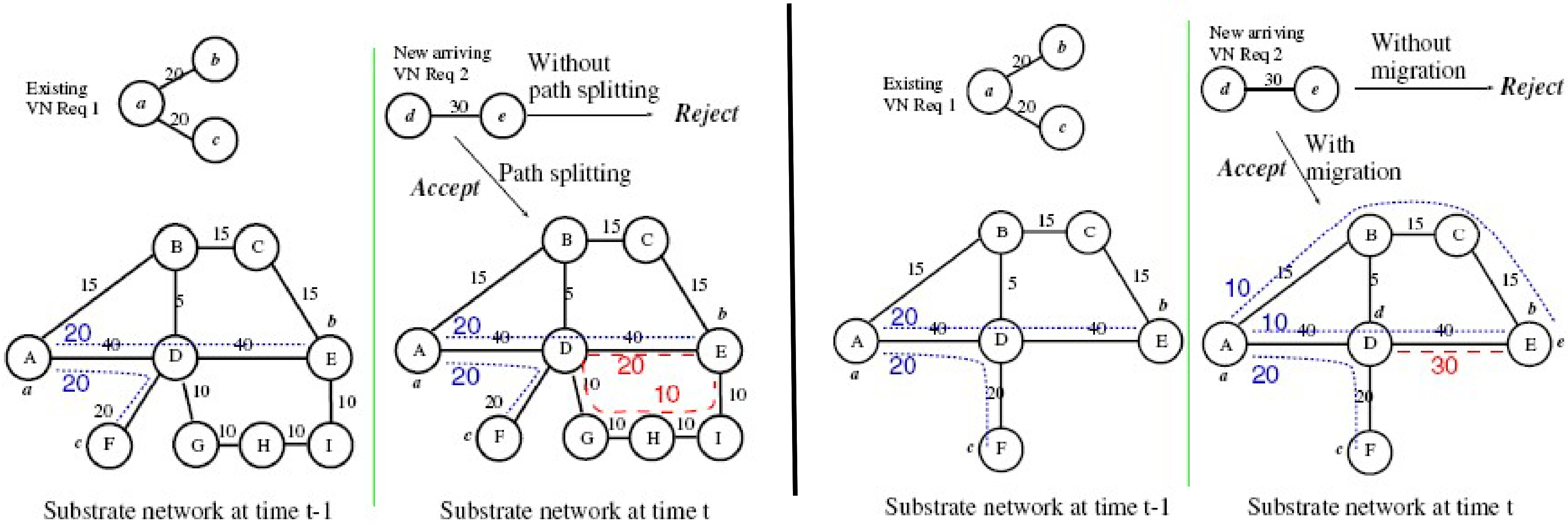


Optimal Node stress

- Bad assumption: the physical network resources is unlimited.

Mapping or Embedding: Online, Dynamic

- Yu et al. “Rethinking Virtual Network Embedding: Substrate Support for Path Splitting and Migration”, Sigcomm 08
- Assume that the substrate network supports path splitting.
- Path optimization (and thus path migration) is carried out at each time slot *t*.



Resource Allocation & Scheduling

- Static: simple but not efficient; dynamic: more efficient but less stable
- Each substrate link periodically reassigns bandwidth shares between its virtual links.
- Method: to max/min a utility function subject to certain constraints such as link bandwidth.
- Problem: not too much flavour of network virtualization – not like in mapping

$$\text{maximize} \quad U(x) = \sum_i u_i(x_i)$$
$$\text{subject to} \quad Rx \leq C$$

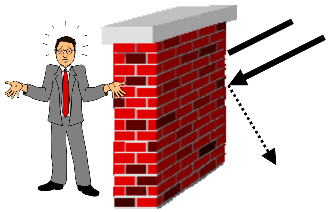
routing matrix or data rate

happiness of user *i*, a function of flow rate

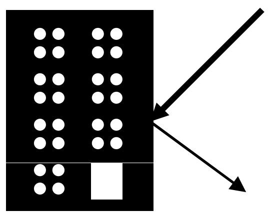
link bandwidths

Issues in Wireless Network

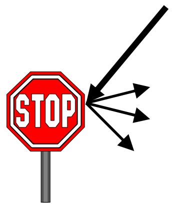
- Wireless links are totally different from wireline!
- There is no confined link and radio transmission is broadcast in nature.
- Wireless link data rate is varying along many factors such as path loss, LoS (line of sight) or not, surrounding interference, transmission power, modulation and coding mechanisms, link distance, link status, multiplexing techniques, ……
- There is no fixed link budget as in wired networks.
- There is no fixed connectivity. E.g., increasing power can enable a node to reach a node that was previously unreachable!
- Everything is so dynamic and mapping seems to be impossible.



shadowing



reflection



scattering

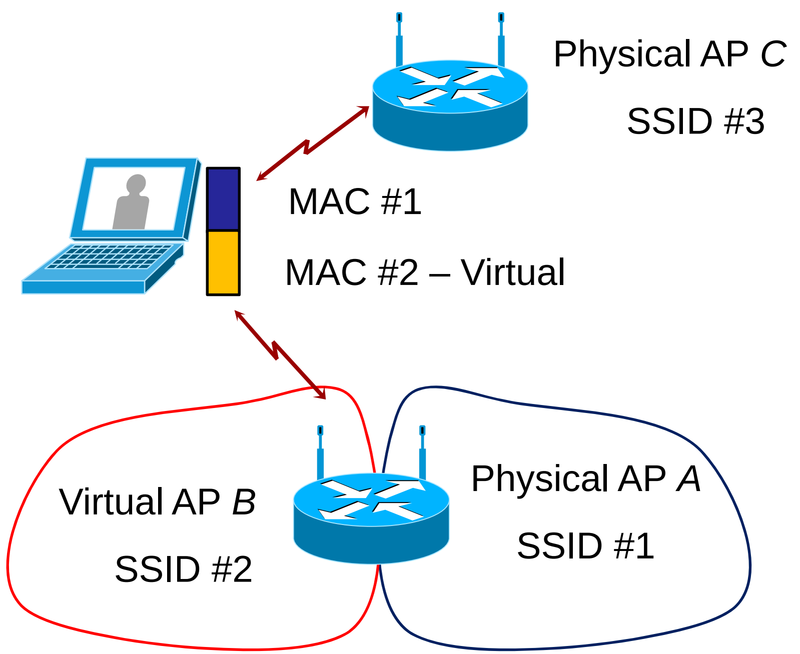
diffraction

What Are People Doing in Wireless NV?

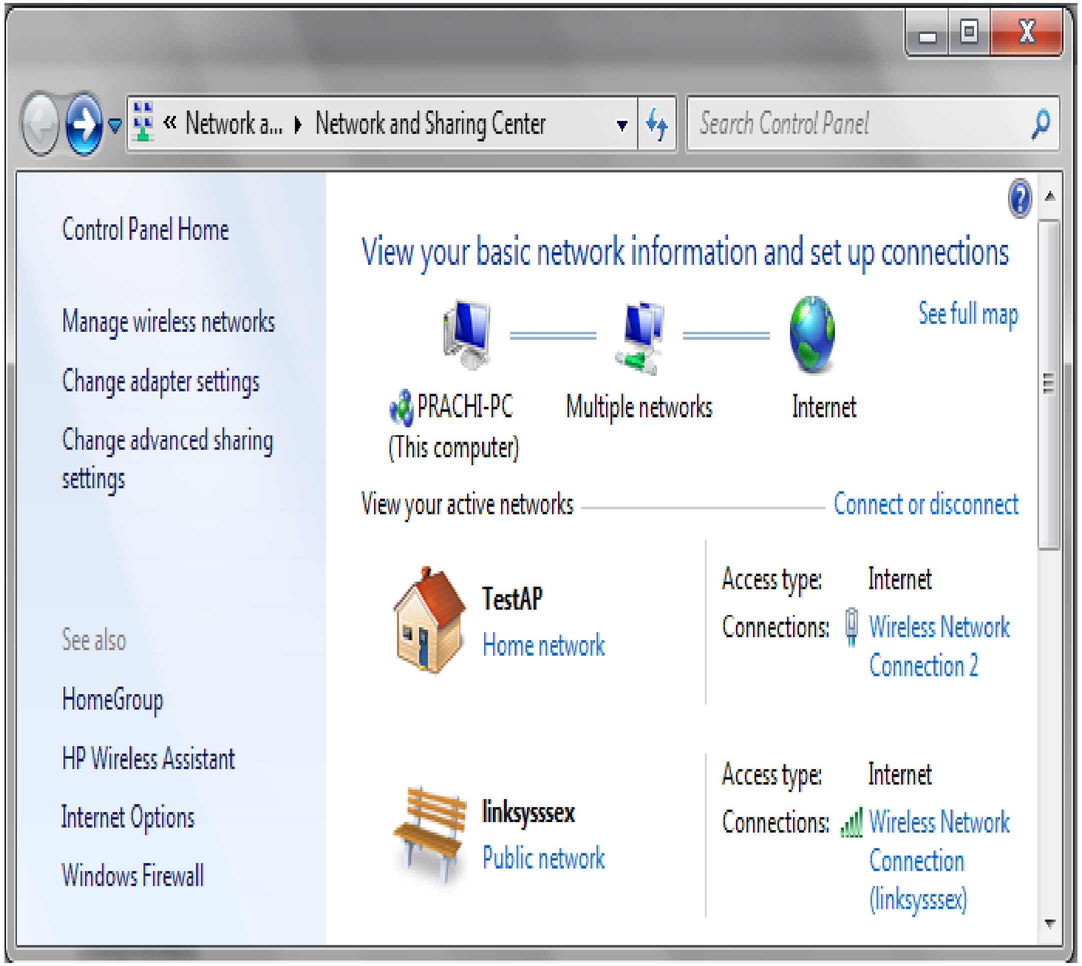
- More experimental than in wireline network.
- Virtualization on ARMS chips
- Virtualization on (Android) nodes – physically virtualize them and may involve OS (e.g., UML: User Mode Linux)
  - A bit more like cloud computing, e.g., using XEN
- Virtualization of WiFi adapter and WiFi Access Point, e.g., Microsoft Virtual-WiFi
- Virtualization of LTE – still on theoretic path-finding and no real system out there yet
- Link virtualization is largely based on the traditional x division multiplexing access technologies, such as SDMA, TDMA, FDMA, OFDMA

What is Essex Doing in Wireless NV?

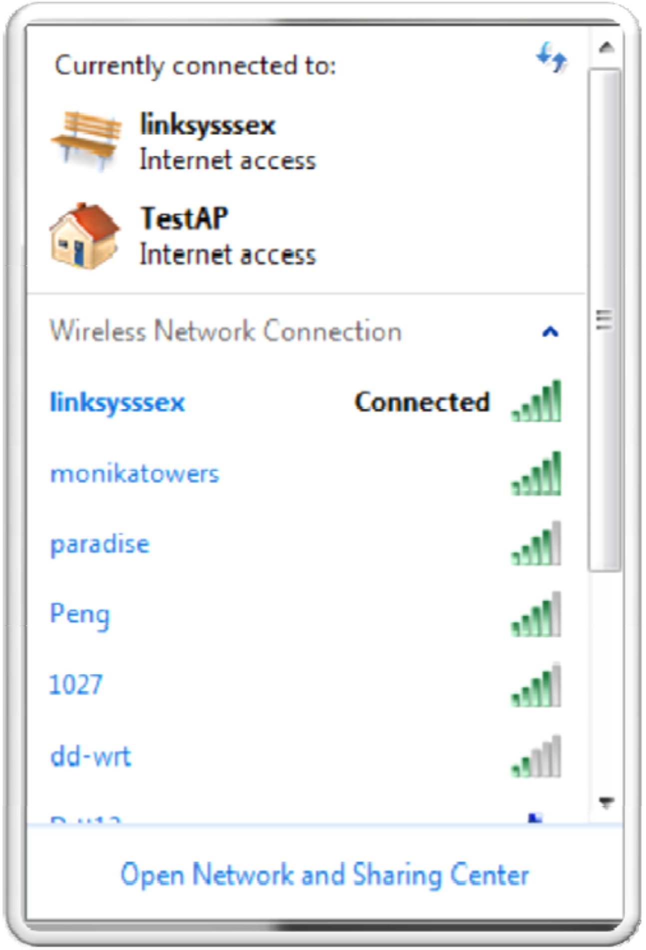
- Some experimental work to start with: AP slitting using MS VirtualWiFi



One PC Connected to Two WiFi APs

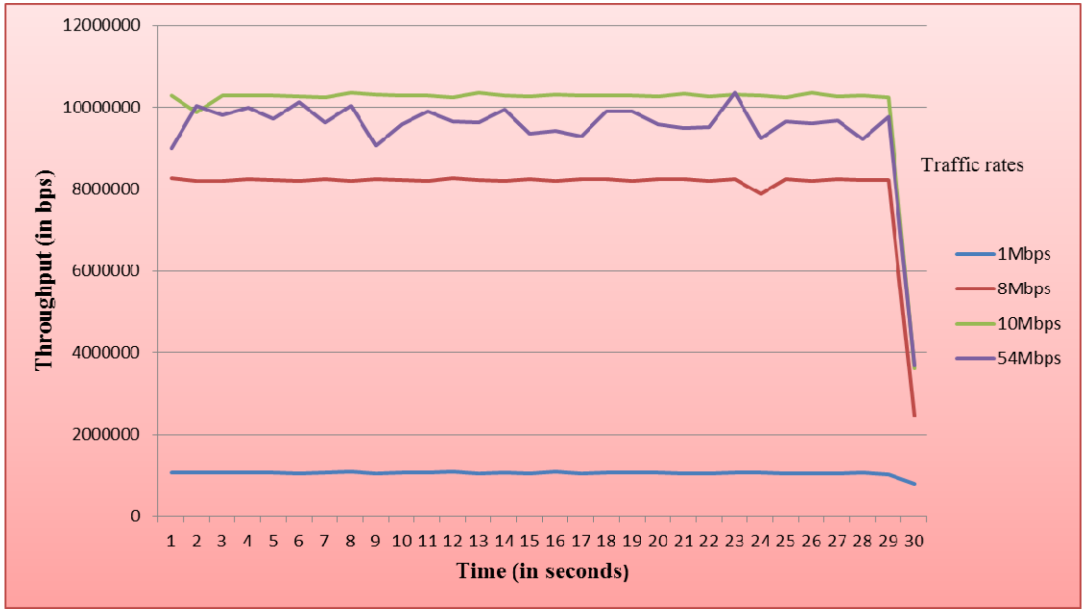


Network Connection Window

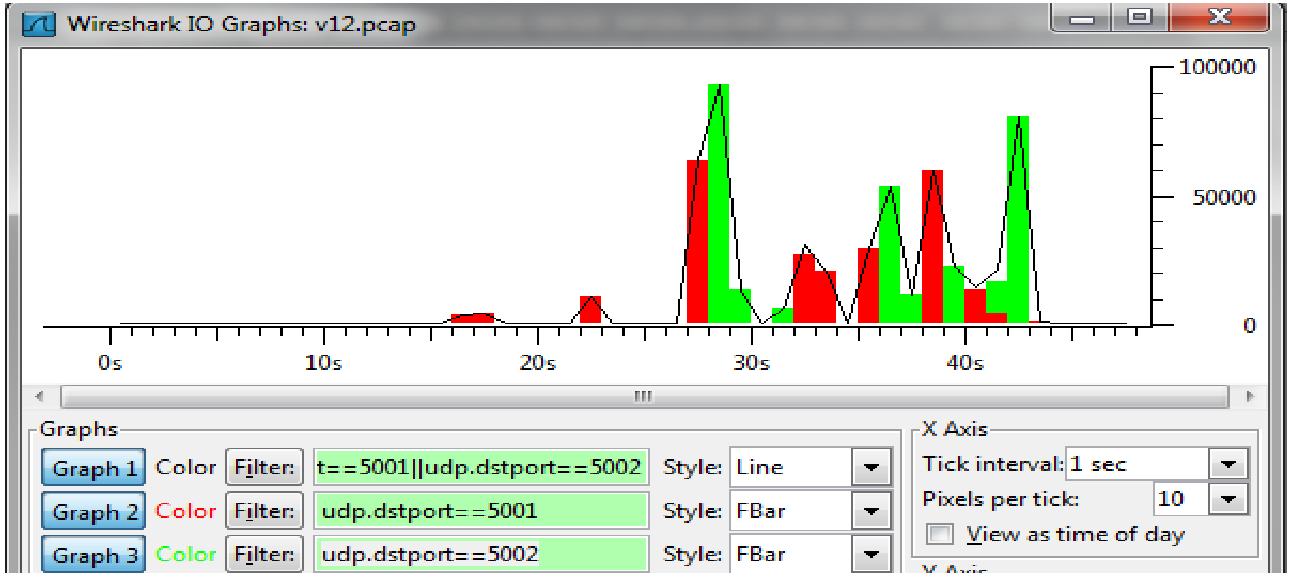


Wireless Connection Window

No Performance Gain After Virtualization



Throughput of one physical WiFi card

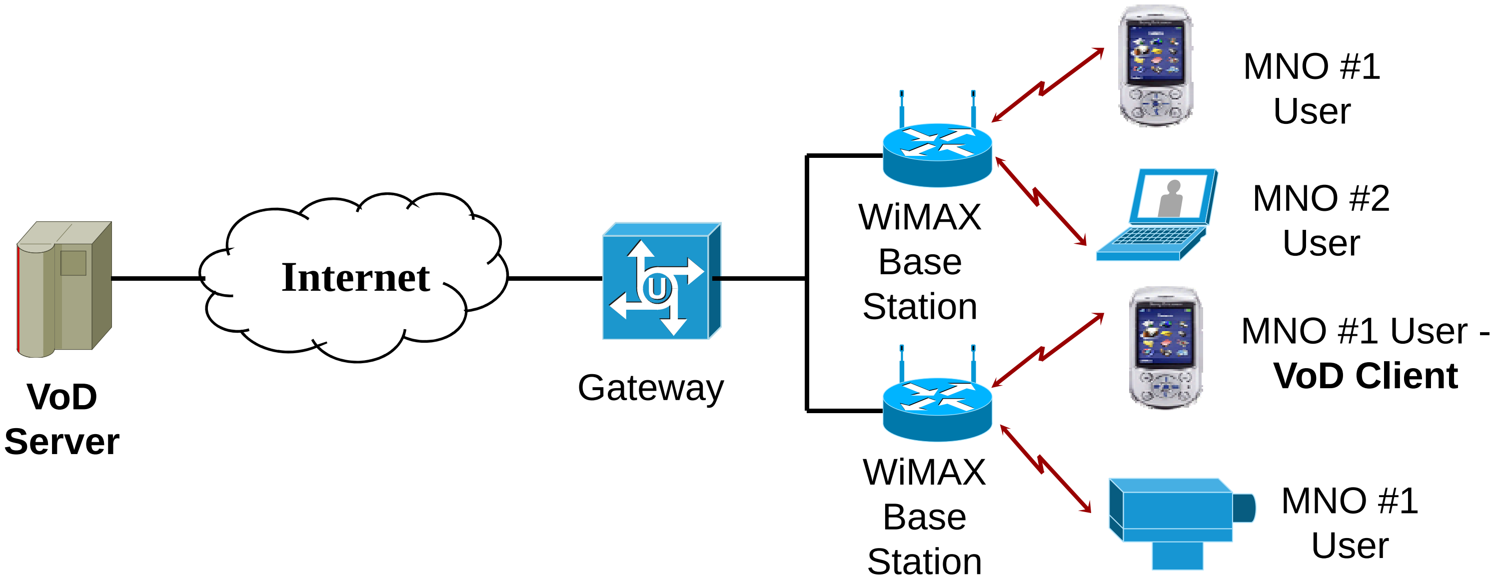


Throughput of two Virtual WiFi cards at 1Mpbs

An Elastic Resource Allocation Algorithm for Wireless Network Virtualization

With Dr. Xiaofeng LU of XDU

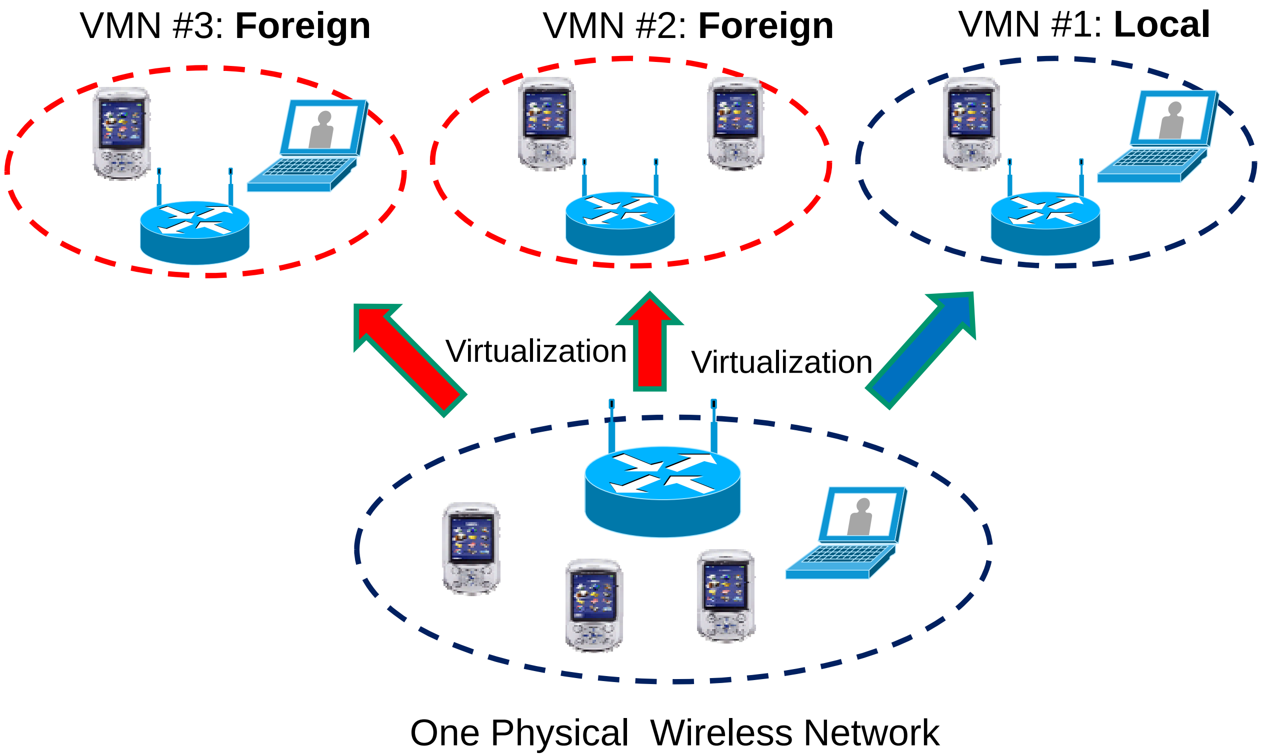
Network Scenario



VoD: Video on Demand

MNO: Mobile Network Operator

WiMAX Network Virtualization



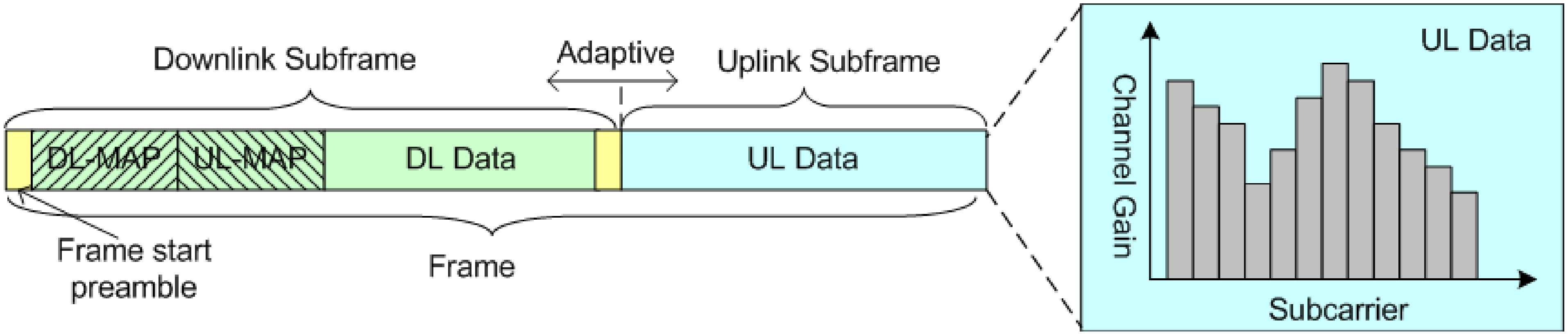
Design Goals

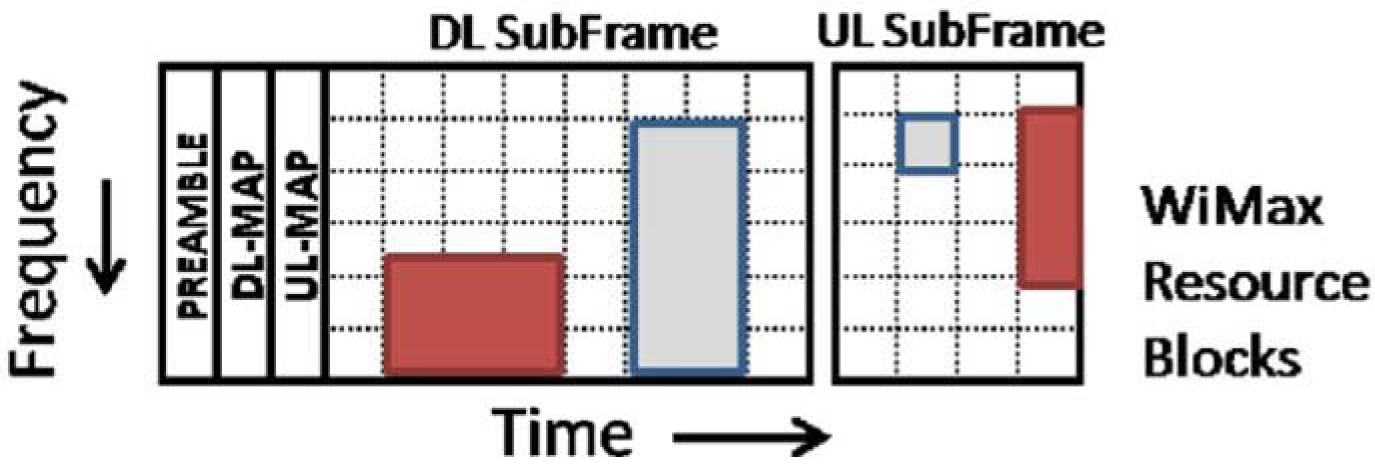
- Isolation: to ensure isolation of network resources across slices, meaning:
  - Passive mode: *any* change in one slice due to new users joining in, mobility of users, fluctuating channel conditions, etc., should not lead to reduction in resource allocation for other slices.
  - Active mode: slices should be able to choose their own resource allocation, scheduling, QoS mechanisms – sometimes also called customization, or elasticity as called in cloud computing
- Resource efficiency: especially in the wireless domain, network operators often attempt to maximize their revenue by keeping the scarce wireless channels occupied as much as possible. Resources in terms of:
  - Time, Frequency, Code
  - Power: energy efficiency

Some OFDMA Terms

- 3G is CMDA; OFDMA is for 4G LTE.
- Slice: a section of the wireless links, in the form of a bundle of wireless channels; Virtual MNO is a slice owner.
- User: a mobile node, can have multiple flows (e.g., video, voice, data at the same time)
- Flow: an independent stream of data of certain characteristics. E.g., a video stream or a ftp session is a flow
- Channel: a physical wireless media, also called carrier
- Sub-channel is called symbol in OFDMA terms
- Sub-carrier, block,
- Frame and sub-frame

WiMAX/OFDMA Frames

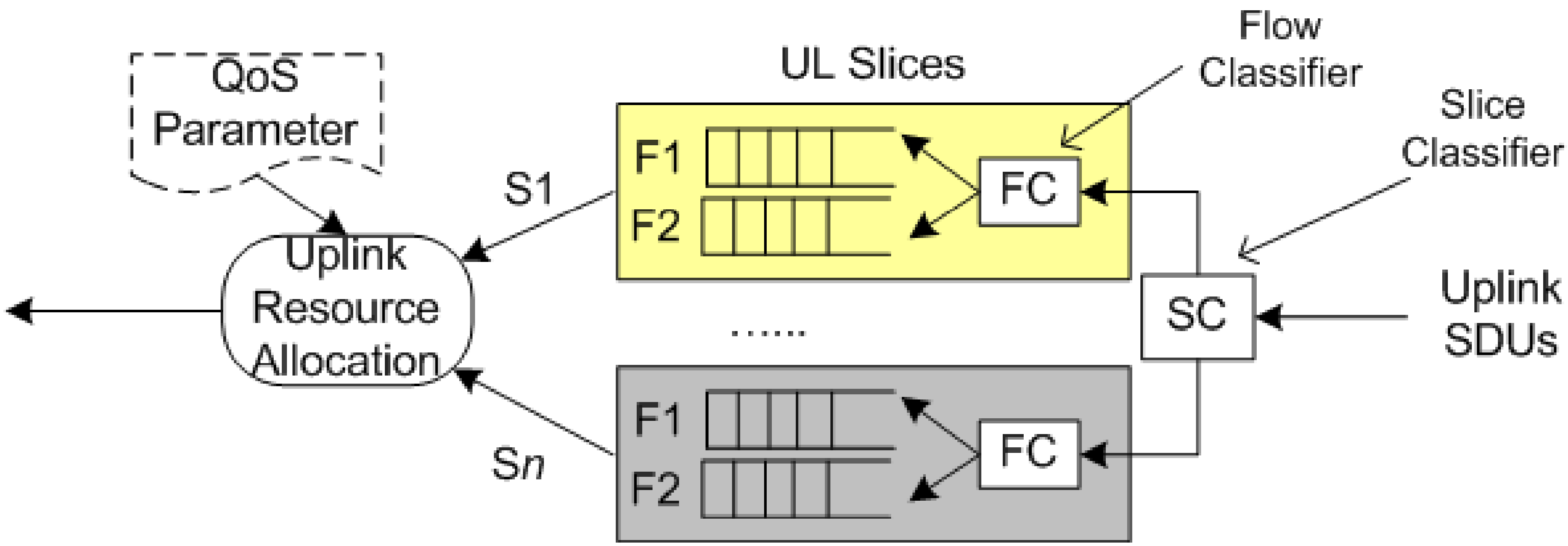




Problem Statement

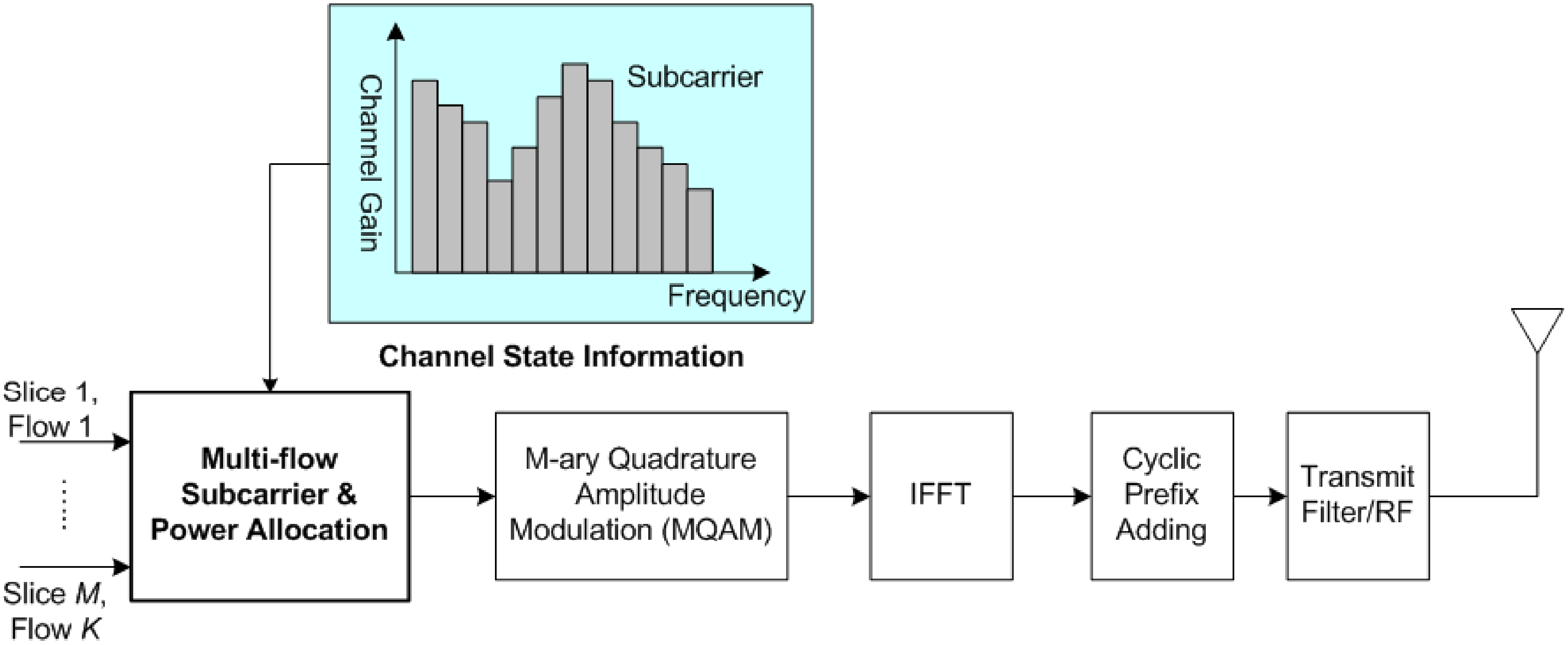
- Assumptions:
  - Each VMNO submits a rate (*rSi)* defining the maximum data rate it needs from the MNO. - this is natural requirement in practice but rarely considered in the literature.
  - Any traffic exceeding this upper limit from this VMNO will not be satisfied but any traffic within this limit will be charged on a pay-as-you-use basis – and thus the corresponding resource allocation mechanisms should be in place to enable this business model.
  - This work considers only uplink which is more difficult than the broadcast downlink.
- To allocate sub-carriers on a per-flow per-slice basis while minimizing the number of sub-carriers used.

MAC Scheme

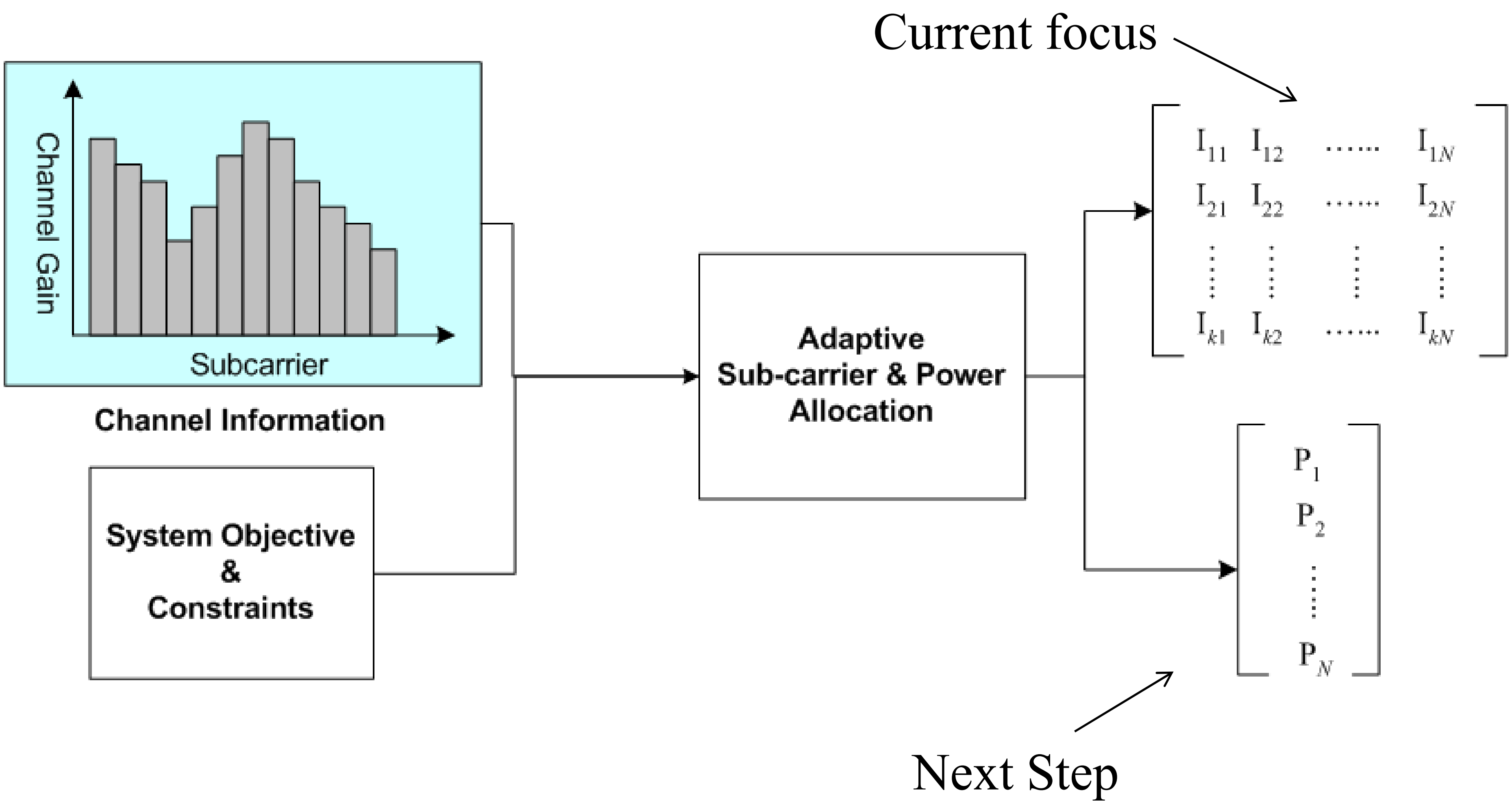


QoS
Parameter
Uplink
Resource
Allocation
S1
Sn
UL Slices
F1
F2
FC
F1
F2
FC
......
Flow
Classifier
Slice
Classifier
SC
Uplink
SDUs

Block Diagram of a Multi-Slice Multi-flow OFDMA Transmitter



Resource Allocation Problem Illustration



r_{S_i}	Data rate requested by slice *Si*
$r_{f,S_i}^{\text{REQ-REAL}}$	Real data rate requirement from flow *f* of slice *Si*
$r_{f,S_i}^{\text{REQ-ALG}}$	The data rate the algorithm can allocate to flow *f* of slice *Si*
$I_{f,c}$	Assignment index indicating flow *f* being allocated to subcarrier *c*
$P_{f,c}$	Power allocated to flow *f* in subcarrier *c*
$h_{f,c}$	Channel gain of flow *f* in subcarrier *c*
$BER_{f,c}^{\text{target}}$	Target BER of flow *f* in subcarrier *c*
Φ	Total bandwidth of the system
P_T	Total transmission power of the system
N_0	Noise power spectral density
N	Number of subcarriers
M	Number of foreign slices
A	Universal set of system Subcarriers
B	The set of subcarriers that are allocated to local network flows

Some Notations

Data Rate Calculation

- Assume that identical power is allocated to each subcarrier and M-ary quadrature amplitude modulation (MQAM) is employed. The BER for an AWGN channel is given by:

$$BER_{f,c} \approx 0.2\exp\left(-\frac{1.5P_{f,c}h_{f,c}^2}{\left(2^{r_{f,c}}-1\right)N_0\dfrac{\Phi}{N}}\right)$$

- Then the maximum data rate of flow *f* in subcarrier *c* is:

$$r_{f,c} = floor\left(\log_2\left(1-\frac{1.5P_{f,c}h_{f,c}^2}{\ln(5BER_{f,c}^{\text{target}})N_0\dfrac{\Phi}{N}}\right)\right)$$

Two Types of Slices

- There are two types of slices in the network:
  - (1) **local slice**, denoted as Slice 0, which is used by the local traffic that is initially generated towards this physical network;
  - (2) **foreign slices,** denoted as Slice 1 to M, which serve traffic flows from VMNOs.
- Since the requirements of VNMOs need to be guaranteed, the resources (i.e., subcarriers) are firstly allocated to Slice 1 to M efficiently.
  - Careful admission control is needed but not covered in this work.

Resource Allocation to Foreign Slices

- The general form of the subcarrier allocation to Slices 1 to M can be described as the following optimization problem:

$$\min \sum_{f \in S_i} \sum_{c \in A} I_{f,c}$$

← To use as small number of the subcarriers as possible.

s. t.

$$\text{AC1}: \quad \sum_{f \in S_i} I_{f,c} \leq 1$$

← One carrier can only be allocated to one flow or to no flow.

$$\text{AC2}: \quad I_{f,c} = \{0,1\}$$

$$\text{AC3}: \quad r_{f,S_i}^{\text{AL}} \geq r_{f,S_i}^{\text{REQ-ALG}}$$

$$\text{AC4}: \quad r_{f,S_i}^{\text{AL}} = \sum_{f \in S_i} \sum_{c \in A} I_{f,c} floor\left(\log_2 \left(1 - \frac{1.5 P_{f,c} h_{f,c}^2}{\ln(5BER_{f,c}^{\text{target}}) N_0 \dfrac{\Phi}{N}} \right) \right)$$

$$= \sum_{f \in S_i} \sum_{c \in A} I_{f,c} r_{f,c}$$

Office Assignment Problem

The above optimization problem is suitable to be converted to *Office Assignment Problem (OAP)*, and use a linear programming (LP)-based branch-and-bound algorithm to solve the problem.

$$\min \quad \boldsymbol{q}_c^{\mathrm{T}} \boldsymbol{x}$$

s. t.

$$\mathbf{A}_{eq}\boldsymbol{x} = \boldsymbol{b}_{eq}$$

$$\mathbf{A}_{neq}\boldsymbol{x} \le \boldsymbol{b}_{neq}$$

$$x_i = \{0,1\},\ \mathbf{x}=[x_1,\cdots x_i \cdots x_n]$$

1. Initialization:
2. Set $A = \{C_1, \cdots, C_N\}$, $P_{f,c} = P_T / N$, $I_{f,c} = 0$, $\boldsymbol{A}_{eq} = []$, $\boldsymbol{b}_{eq} = []$
3. Create optimization coefficients:
4. for all $f \in S_i, c \in A$
5. $(\boldsymbol{x})_j = I_{f,c}$
6. $(\boldsymbol{q}_c)_j = 1$
7. $r_{f,c} = floor\left(\log_2\left(1 - \dfrac{1.5 P_{f,c} h_{f,c}^2}{\ln(5BER_{f,c}^{\text{target}}) N_0 \dfrac{\Phi}{N}}\right)\right)$
8. end for
9. for all $f \in S_i$
10. $A_{neq}(i,:)$, $b_{neq}(i,:)$ = the constraint of (AC1)
11. $A_{neq}(M+i,:)$, $b_{neq}(M+i,:)$ = the constraint of (AC3)
12. end for
13. Solve OAP to get $I_{f,c}$

Resource Allocation to Local Slice

$$\max \quad \sum_{f} r_{f,S_0}^{\mathrm{AL}}$$

s. t.

$$\text{BC1:} \quad r_{f,S_i}^{\mathrm{AL}} = \sum_{f \in S_i} \sum_{c \in B} I_{f,c}\, floor\left(\log_2 \left(1 - \frac{1.5 P_{f,c} h_{f,c}^2}{\ln(5BER_{f,c}^{\mathrm{target}}) N_0 \dfrac{\Phi}{N}} \right) \right)$$

$$= \sum_{f \in S_i} \sum_{c \in B} I_{f,c} r_{f,c}$$

$$\text{BC2:} \quad \sum_{f \in S_i} I_{f,c} = 1$$

$$\text{BC3:} \quad I_{f,c} = \{0,1\}$$

- to maximize its throughput.
- And there is no rate requirement and only BER constraint is considered
- can use OAP to solve the problem.

1. Initialization:

2. Set $P_{f,c} = P_T / N$, $I_{f,c} = 0$, $\boldsymbol{A}_{neq} = []$, $\boldsymbol{b}_{neq} = []$

3. Create optimization coefficients:

4. for all $f \in S_i, c \in B$

5. $(\boldsymbol{x})_j = I_{f,c}$

6. $$r_{f,c} = floor\left(\log_2\left(1 - \frac{1.5P_{f,c}h_{f,c}^2}{\ln(5BER_{f,c}^{\text{target}})N_0\frac{\Phi}{N}}\right)\right)$$

7. $(\boldsymbol{q}_c)_j = r_{f,c}$

8. end for

9. for all $f \in S_i$

10. $\boldsymbol{A}_{eq}(i,:)$, $b_{eq}(i,:)$ = the constraint of (BC2)

11. end for

12. Solve OAP to get $I_{f,c}$

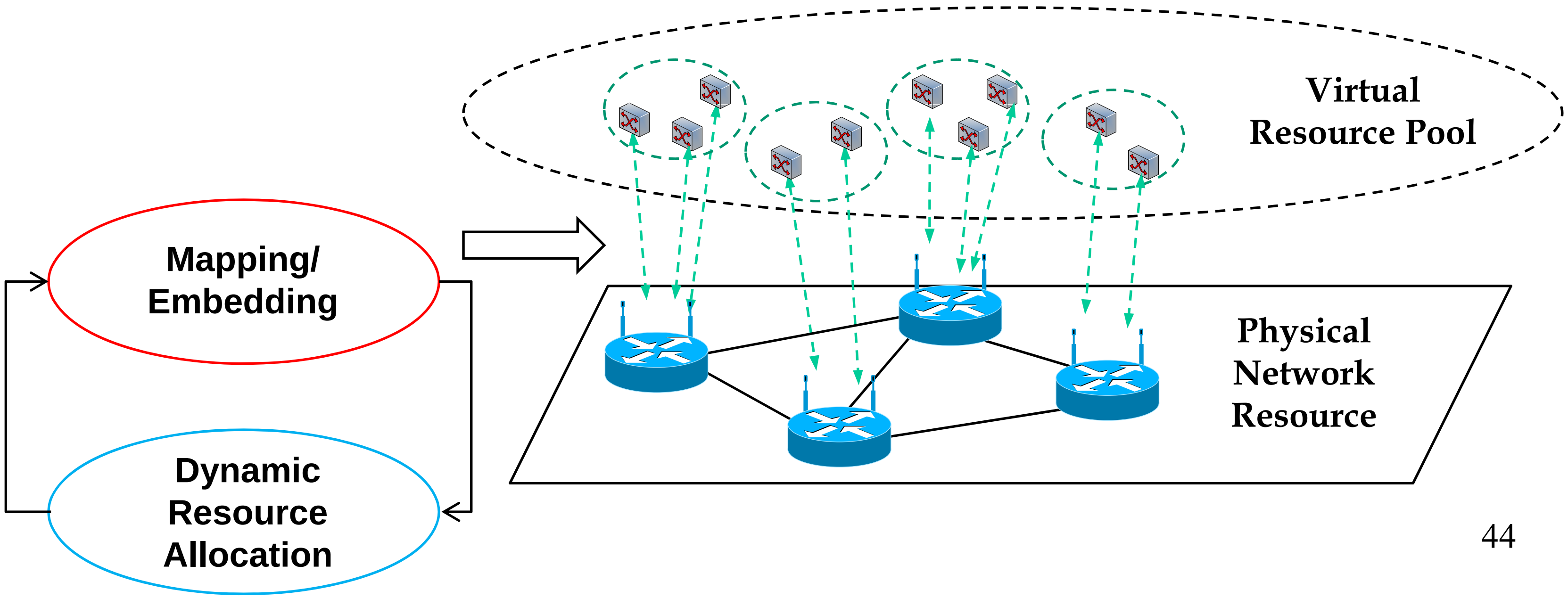
Overall Algorith

Input: M , r_{S_i} , $r_{f,S_i}^{\text{REQ-REAL}}$

1. for i=1 to M *// foreign slice*
2. if $\sum_{f \in S_i} r_{f,S_i}^{\text{REQ-REAL}} \leq r_{S_i}$, then
3. $r_{f,S_i}^{\text{REQ-ALG}} = r_{f,S_i}^{\text{REQ-REAL}}$
4. else
5. $r_{f,S_i}^{\text{REQ-ALG}} = \dfrac{r_{f,S_i}^{\text{REQ-REAL}}}{\sum_{f \in S_i} r_{f,S_i}^{\text{REQ-REAL}}} r_{S_i}$
6. end for
7. Choose $\{S_i\}, i = 1 \cdots M$ *// foreign slices*
8. Call ALG #1
9. Set $B = \left\{ C_l \,\middle|\, \sum_{\substack{f \\ l \in A}} I_{f,l} = 0 \right\}$
10. Choose $\{S_i\}, i = 0$ *// local slice*
11. Call ALG #2

Future Thoughts: Resource Allocation

- How to combine resource allocation/scheduling with mapping, e.g.,
  - How to change power to enable otherwise impossible mapping on one hand; and how to carry out proper mapping in order to save power on the other hand
  - How to use control theory to model this interactive system
  - Cross-layer design (CLD)
  - …



Future Thought: Node Virtualization

- Not possible to use commercial product
- To use USRP (Universal Software Radio Peripheral) so as to:
  - Introduce two different protocol stacks -> isolation
  - Design different MAC mechanisms in terms of resource allocation and scheduling, etc -> elasticity, resource efficiency, energy efficiency
  - Even have different RF fronts (e.g., both WiFi and WiMAX and LTE)! Or even turn a WiFi AP into a WiMAX base station – too elastic?
  - Ettus Ltd. – bought by NI

Agenda

- Motivation: why FIA?
- Network Virtualization
- Post-IP Future Internet Architecture: Information Centric Networking
- Converged Network & Service Test-bed
- Q&A

ICN: Information Centric Networking

- IP may be "the" problem! Get rid of IP so called post IP or beyond IP.
- ICN: Information Centric Networking
  - CCN: Content Centric Networks by Van Jacobsen
- EU FP7 Project PURSUIT (Publish-Subscribe Internet Technology)
  - It is *information* rather than *machine (or IP)* that is named and addressed.
  - U. of Essex is a partner of the PURSUIT Consortium.

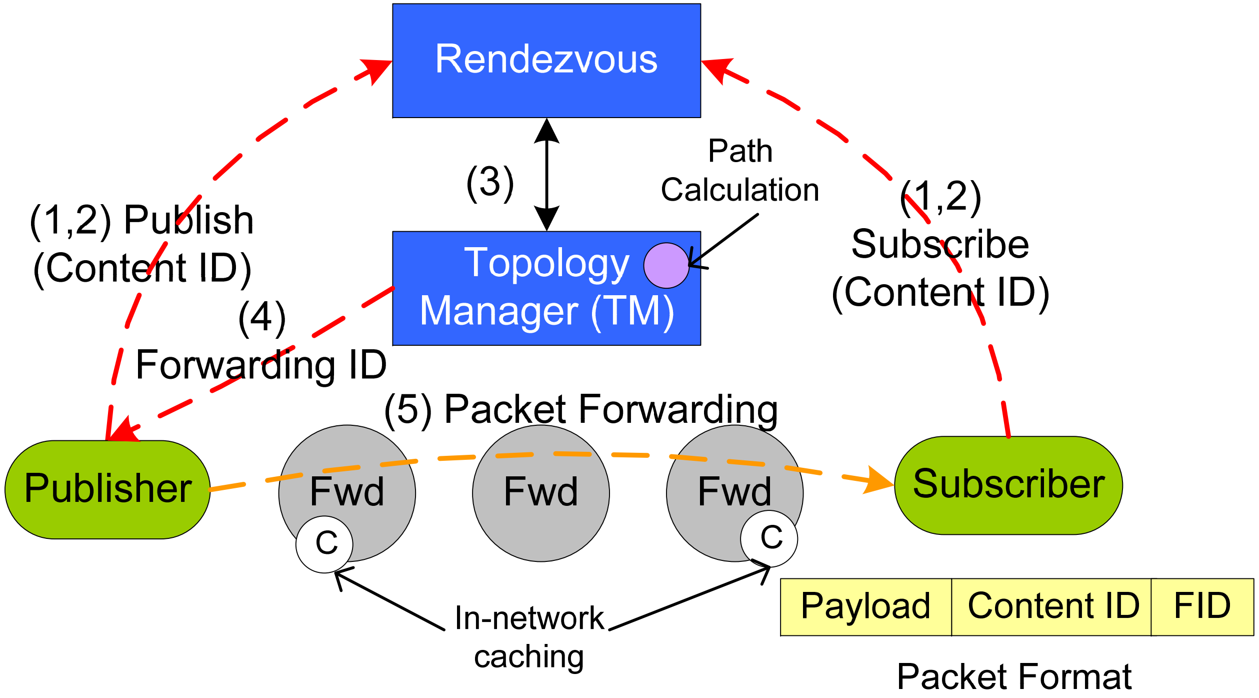
Some Features of ICN

- Source routing:
  - source nodes, rather than intermediate nodes (routers), to decide the route
  - *(ref. DSR – Dynamic Source Routing in Wireless Sensor Networks)*

- Publish-subscribe:
  - At network layer, not application layer (like P2P)
  - Inherently content centric;
  - Natural to some applications
  - Seems to solve some current problems, especially the power of senders over receivers

A Post-IP System Architecture – PURSUIT View

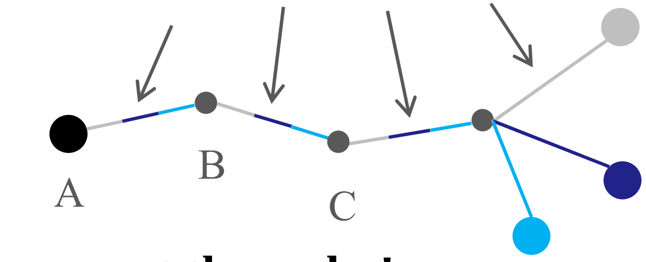
EU FP7
Project
PURSUIT



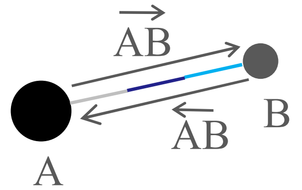
- **R**endezvous: matching pub and sub
- **T**opology Manager (TM): topology knowledge, path (or delivery tree) calculation
- **F**orwarding: store and forward, fast delivery (separation of control and data plane), using Bloom Fliter (next slide)
- **M**ore: in-network caching, security, scoping, naming, …

Creation of Forwarding ID

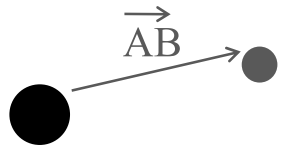
Links are named with *Link-IDs*



not the nodes!



Each link has two identifiers *(Link-ID)*



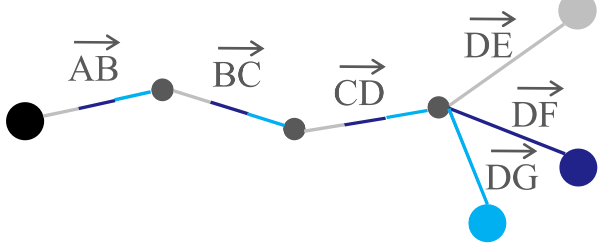
Each *Link-ID* is a m-bit name where only k bits are set to 1 with k<<m

k bits

0	1	0	0	0	0	1	0	0	0	0	1	0	0

m bits

The multicast route



$\overrightarrow{AB}$	1	0	0	1	0	0	0	0	0	0	0	0	0	1	OR
$\overrightarrow{BC}$	1	0	0	0	0	0	0	0	0	1	0	0	0	1	OR
$\overrightarrow{CD}$	0	0	0	1	0	0	0	0	0	1	0	0	0	1	OR
$\overrightarrow{DE}$	1	0	0	0	0	0	1	0	0	0	0	1	0	0	OR
$\overrightarrow{DF}$	0	0	0	1	0	0	1	0	0	0	0	1	0	0	OR
$\overrightarrow{DG}$	1	0	0	0	0	0	0	0	0	0	0	1	0	1	
	1	0	0	1	0	0	1	0	0	1	0	1	0	1	

Example

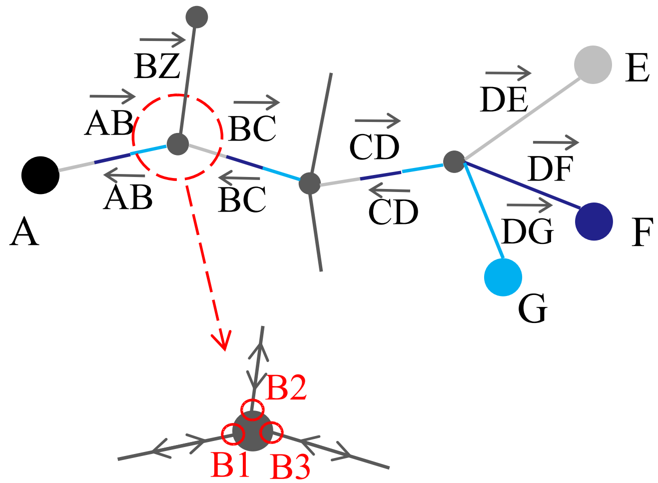
k=5

m=248

n. of links= $\frac{m!}{(m-k)!} \approx 9\ 10^{11}$

The whole multicast route is encoded in the **Bloom filter** called **z-filter** and it is written in the packet header.

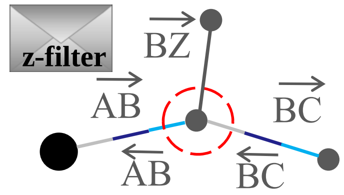
BF-based Forwarding



Interface	Link	Link-ID
B1in	AB	10010000000001
B1out	BA	00100001000001
B2in	ZB	00000000010101
B2out	BZ	10000000000101
B3in	CB	10001100000000
B3out	BC	10000000010001

In each node the forwarding table contains only the Link-ID of the links connecting that node

When a packet reaches a node the z-filter ZF is ANDed with the Link-ID of all the outgoing links of the node.

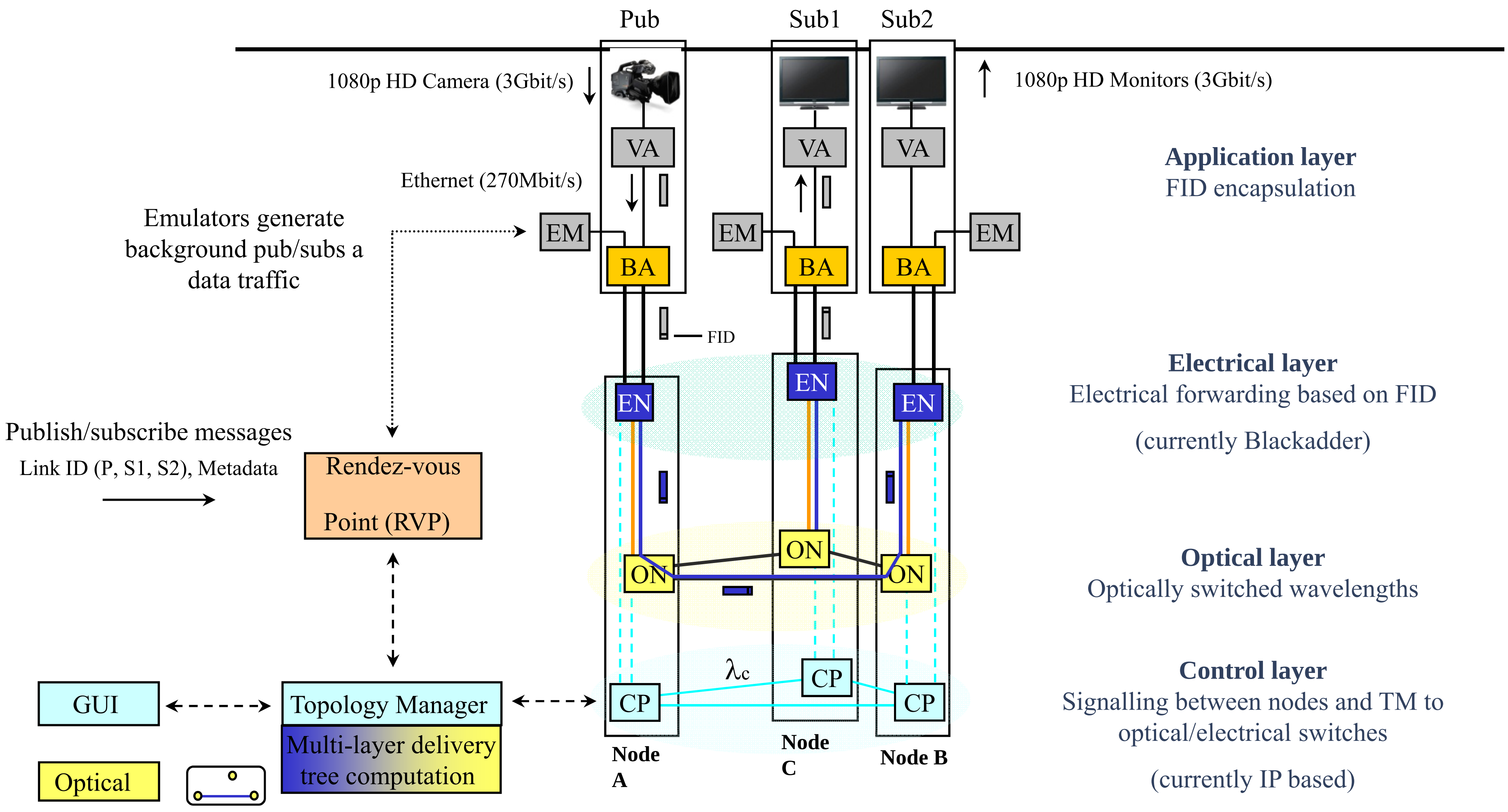


The packet is forwarded through the link if:

ZF AND Link-ID = Link-ID

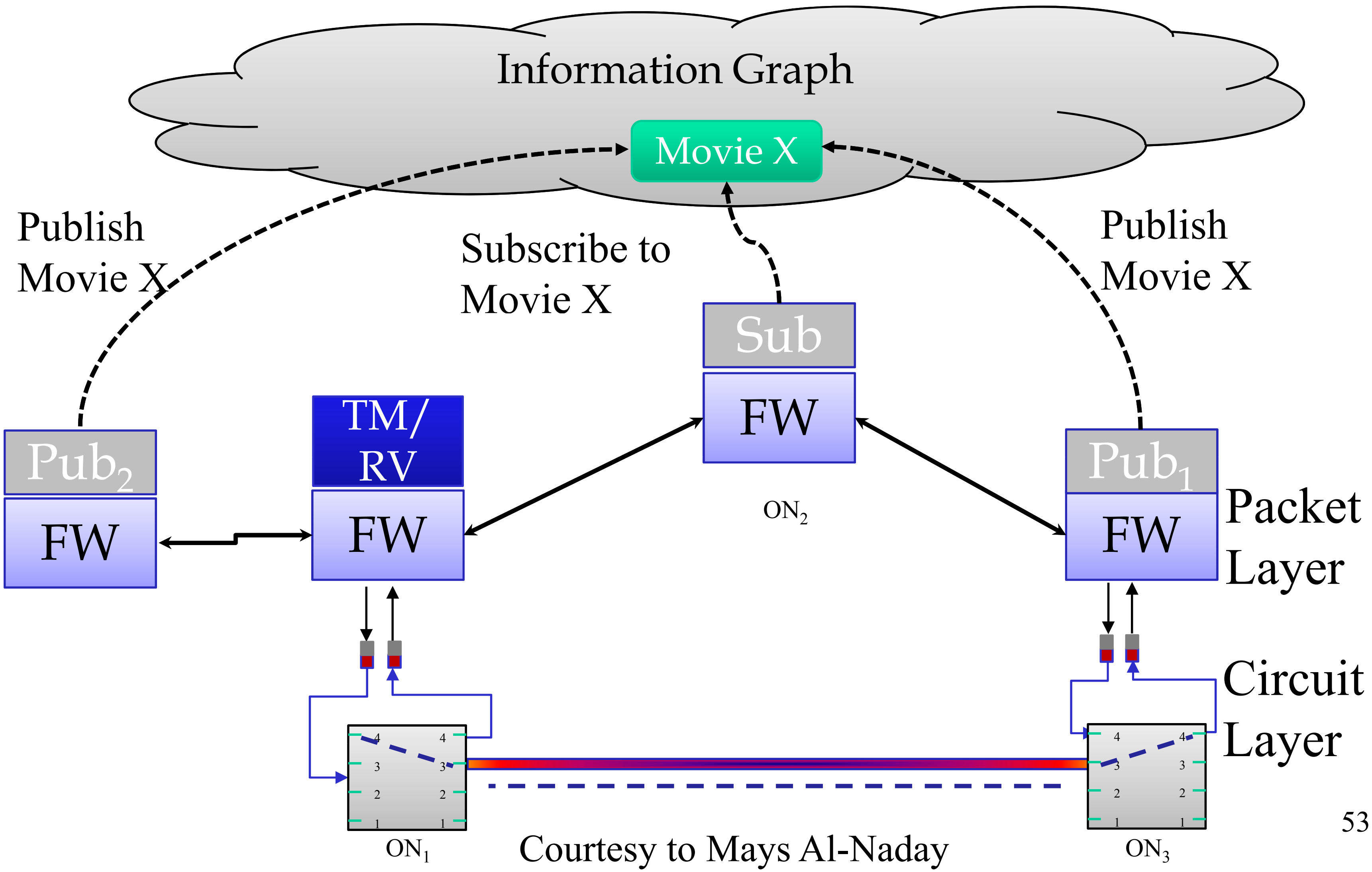
This kind of routing is completely **STATELESS**. It is source routing based where forwarding and routing are independent.

A Setup Example



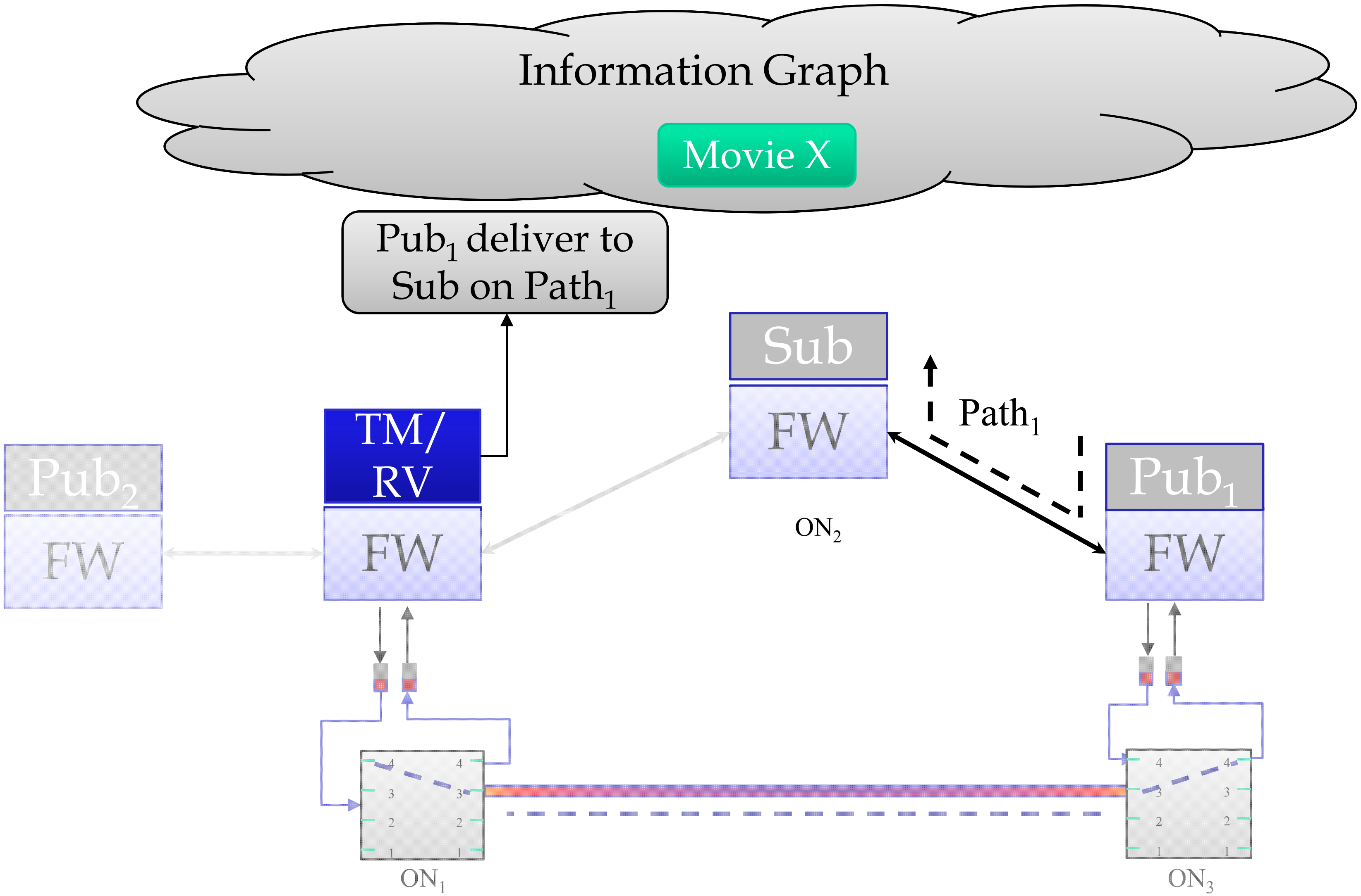
VA	Video Adaptor (HD to SD Dirac CODEC + Ethernet encapsulation)
BA	Blackadder (Forwarding ID Encapsulation)
EN	Forwarding Nodes (based on FID)
ON	Optical nodes (optical wavelength switches)
CP	Topology Manager (out-of-band signalling) – using λc
EM	Pub/sub emulators. Create random or pre-defined pub/sub requests with subsequent data plane traffic

Network Topology Under Consideration

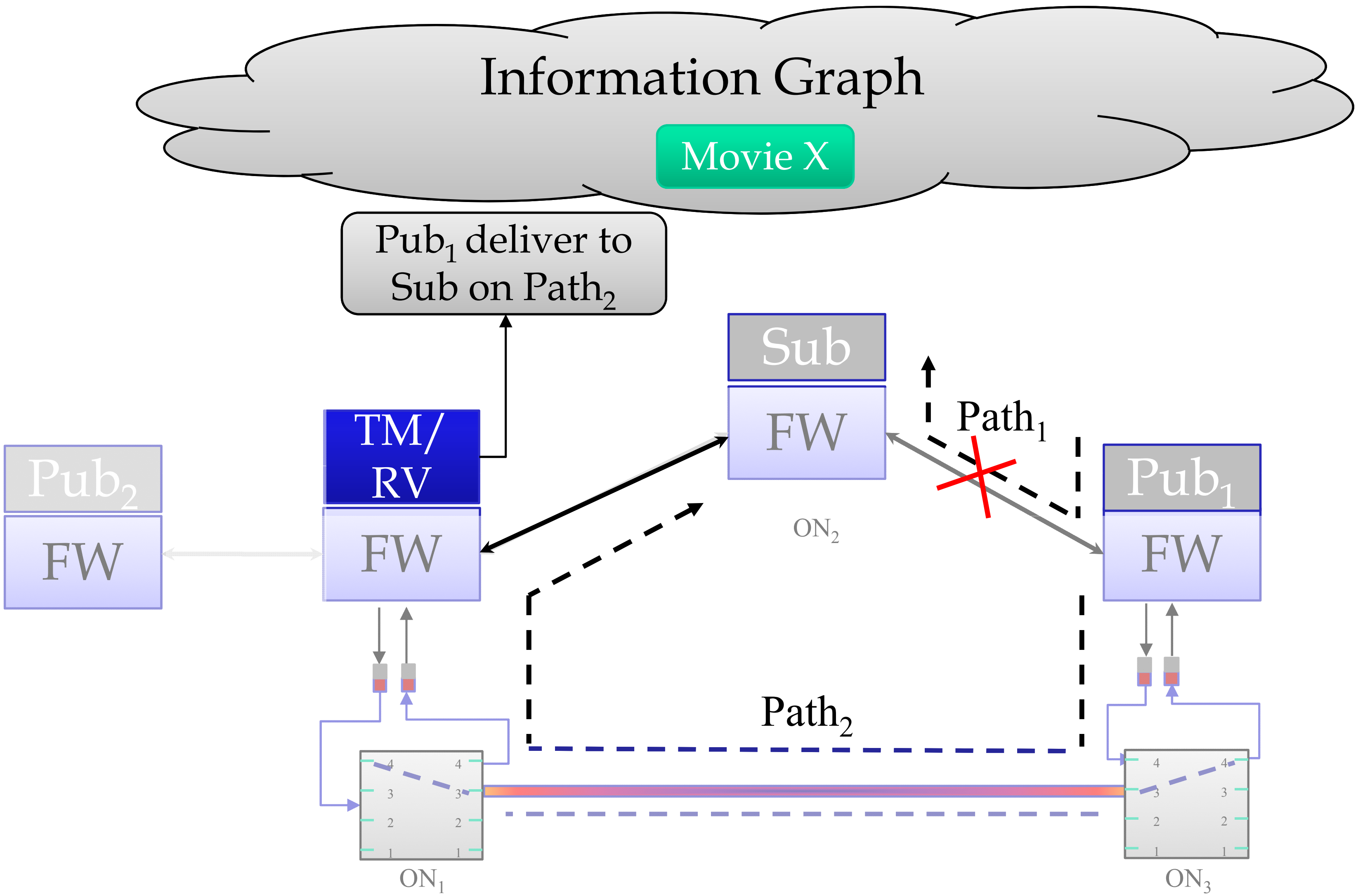


Courtesy to Mays Al-Naday

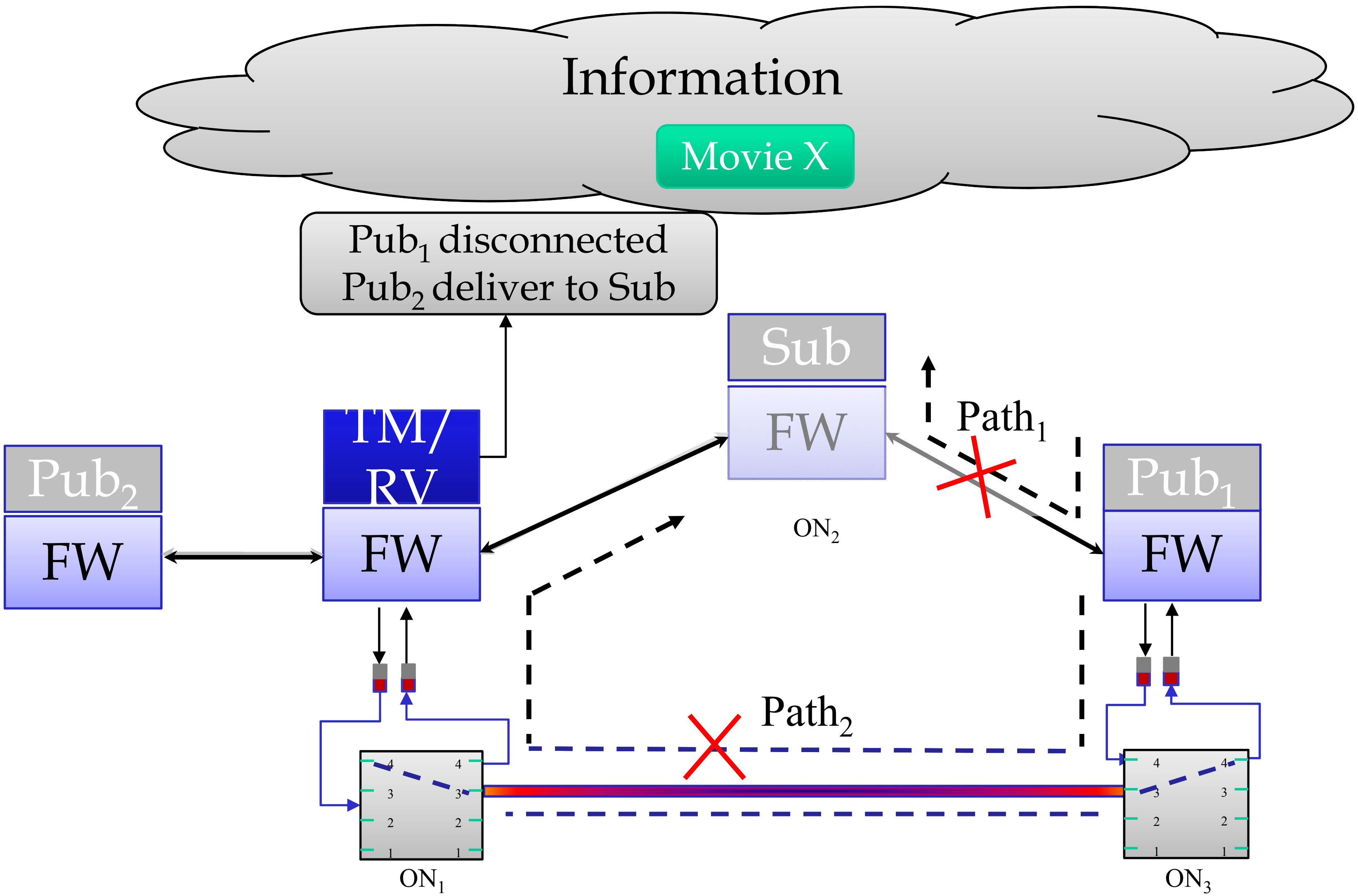
Network Resiliency - 1



Network Resiliency - 2



Information Resiliency



How to Proceed?

- Simulator: developed by Essex NCL
  - Open source, on top of OMNet++
  - https://sourceforge.net/projects/pubsubsim/
  - Major functions: pub-sub, bloom filter, path calculation, packet forwarding, etc.

- Experiments: Blackadder from PURSUIT (by Cambridge)
  - Open source
  - Link: upon request

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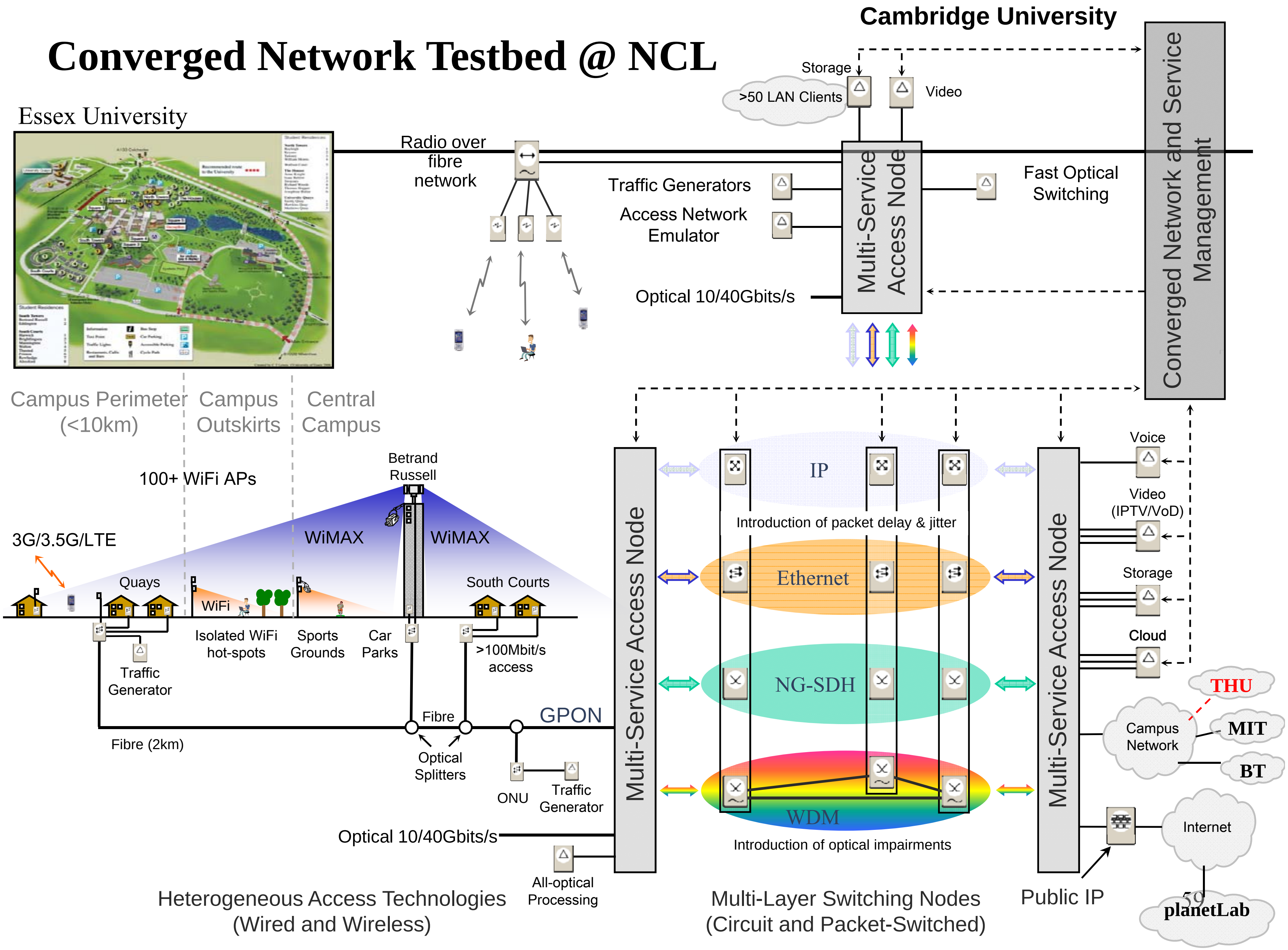
Converged Network Testbed @ NCL



WiMAX/WiFi Network

Bertrand Russell Tower (65m)

- Pan/tilt 60° sector antennas (2.5,3.5 & 5.8GHz)
- Fixed 60° sector antenna (5.8GHz) towards Wivenhoe
- Dome surveillance camera
- Camera and antenna GPS coordinate controlled

- Wivenhoe subscriber unit (2mile
- 20Mbit/s symmetrical services

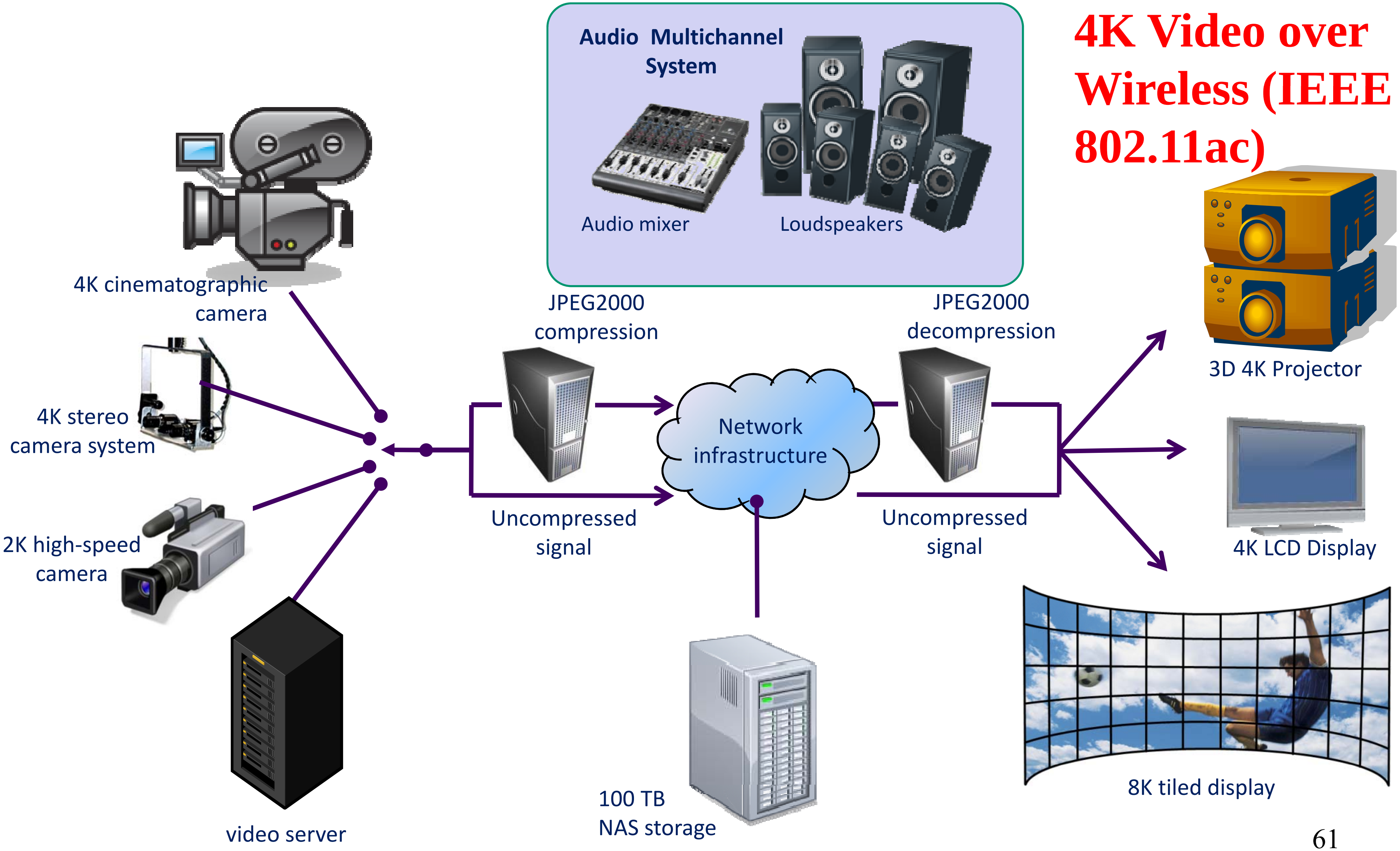
- WiMAX to Wi-Fi units
- WiFi hotspots
- WiMAX connected cameras for excellent wireless quality

WiMAX antenna

WiFi antenna (100m radius)

High Performance Media Networks

4K Video over Wireless (IEEE 802.11ac)



Contact, Q&A

Thanks for your attentions!

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