QoS Challenges for Wireless Broadband: WLAN, Wireless Ad Hoc and WiMAX

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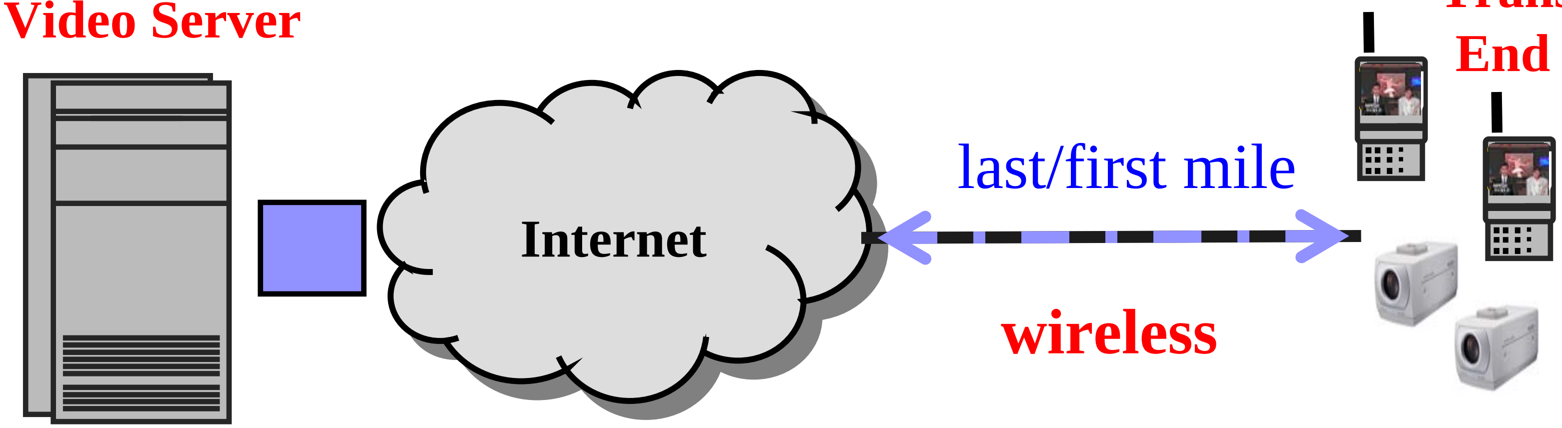
Talk Outline

- QoS Challenges for Wireless Video Networking
- Airtime Fairness Design for WLAN Infrastructure Camera Networks
- Information Broadcasting for Distributed WLAN Ad-Hoc Camera Networks
- Joint Scheduling and Resource Allocation for Video Multicast over WiMAX
- Conclusion

End-to-End QoS Video Networking over Wireless



Video Server

Internet

last/first mile

wireless

Receiving & Transmitting End Clients

Best-effort packet network

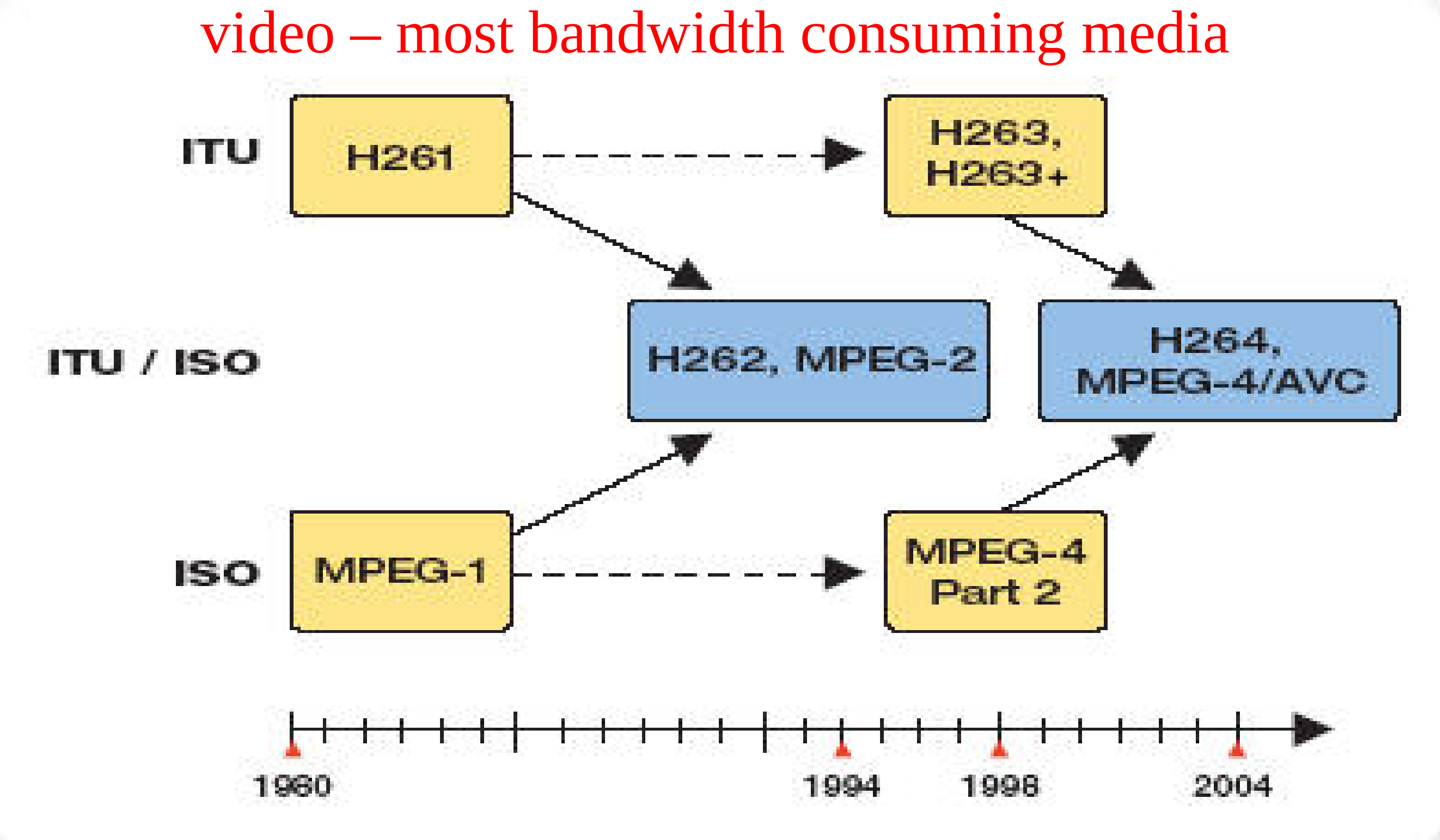
- limited bit-rate
- variable throughput
- variable loss
- variable delay

Wireless error sources

- radio noise and interference
- attenuation
- dispersion
- multi-path interference

Video Coding Evolution

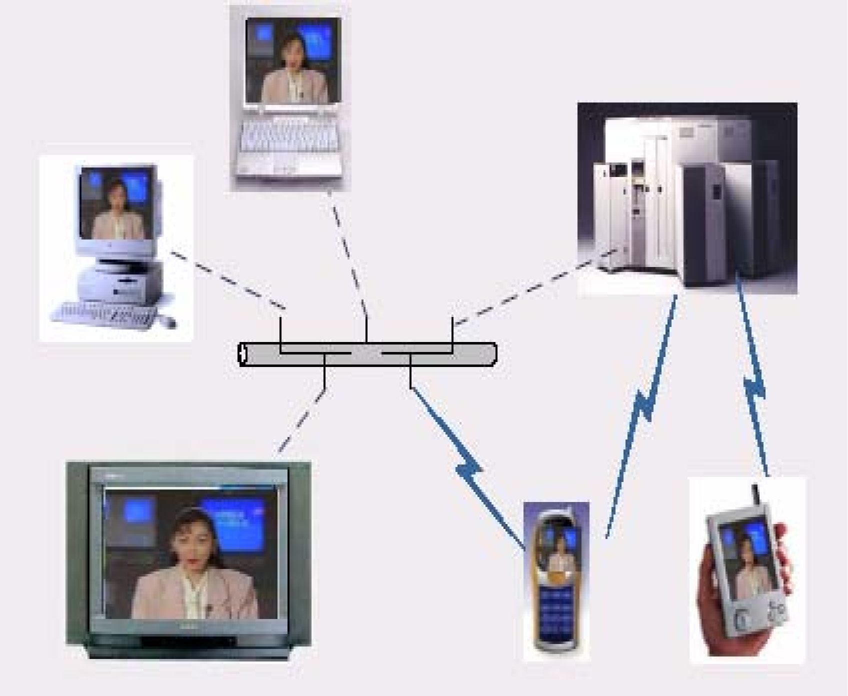
video – most bandwidth consuming media



Microsoft **Windows Media Player,** Apple **Quicktime, and** RealSystems **Real Player**

Adapting to Wireless Heterogeneous Networks

- Microsoft: fast streaming technology
- RealSystems: G2 SureStream technology
- Adaptive Encoding Rate
- Rate Transcoding
- Scalable Video Coding
  - H.264 based (MPEG4 AVC scalable extension, HHI 2007)
  - Temporal, Spatial, and SNR scalability



H.264 Scalable Video
How Many Layers Are Enough?

B0(QCIF@7.5) 67.66 Kbps

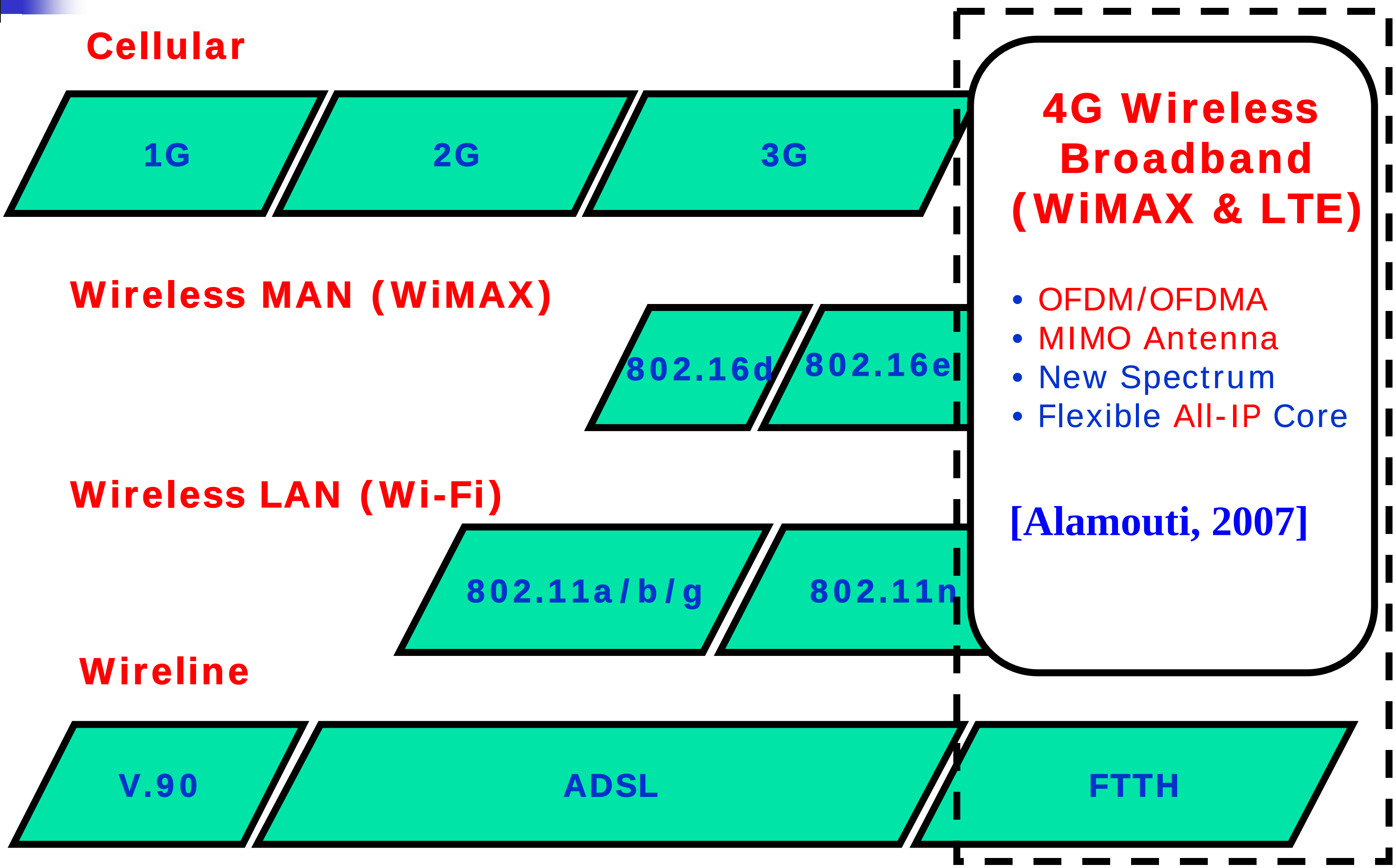
B0+E1(QCIF@15.0) 101.77 Kbps

B0+E1+E2+E3(CIF@15.0) 346.92 Kbps

B0+E1+E2(CIF@15.0) 187.19 Kbps

B0+E1+E2+E3+E4(CIF@ 30.0) 522.77 Kbps

Moving Toward All-IP Wireless Broadband



Cellular

1G

2G

3G

Wireless MAN (WiMAX)

802.16d

802.16e

Wireless LAN (Wi-Fi)

802.11a/b/g

802.11n

Wireline

V.90

ADSL

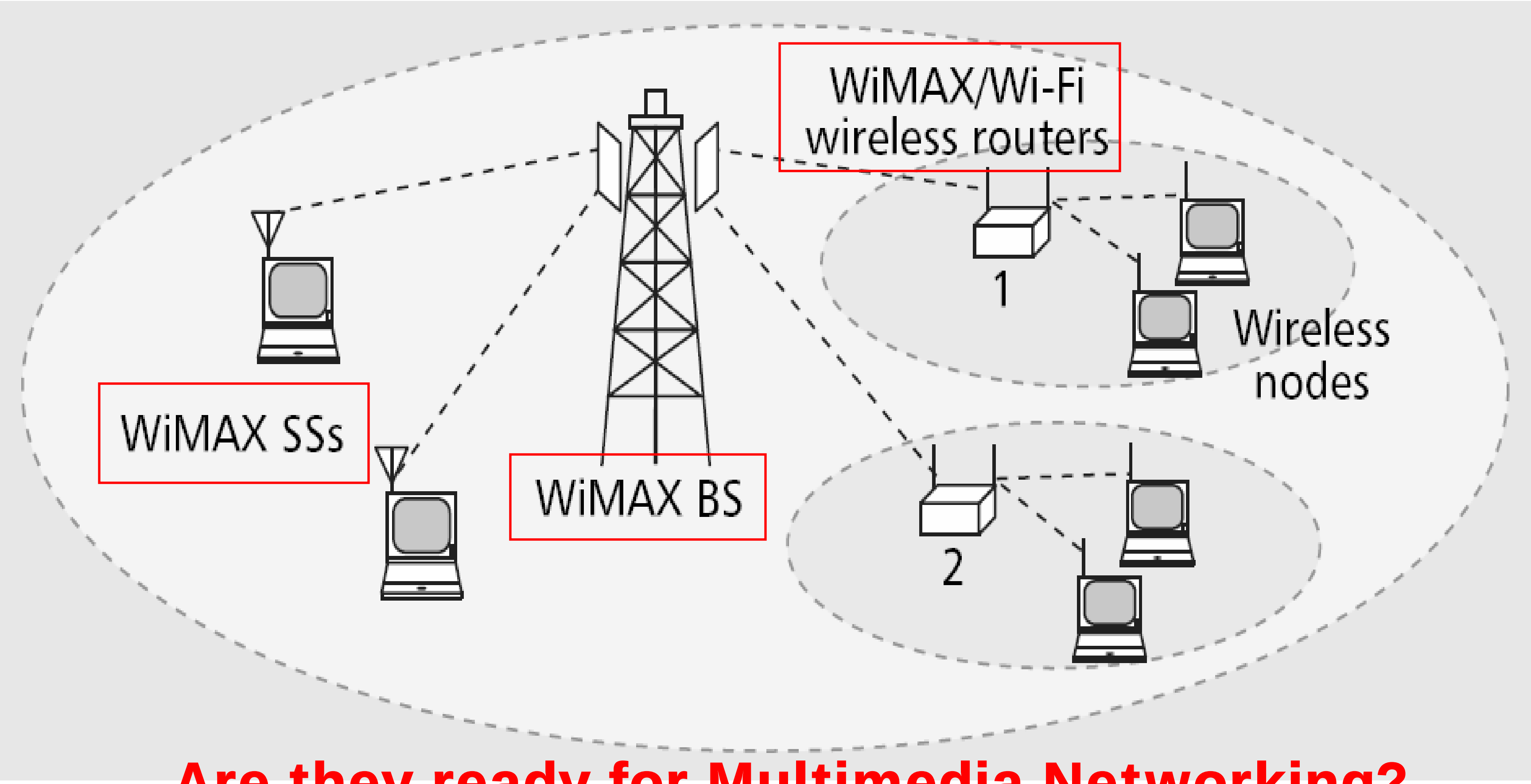
FTTH

4G Wireless Broadband (WiMAX & LTE)

- OFDM/OFDMA
- MIMO Antenna
- New Spectrum
- Flexible All-IP Core

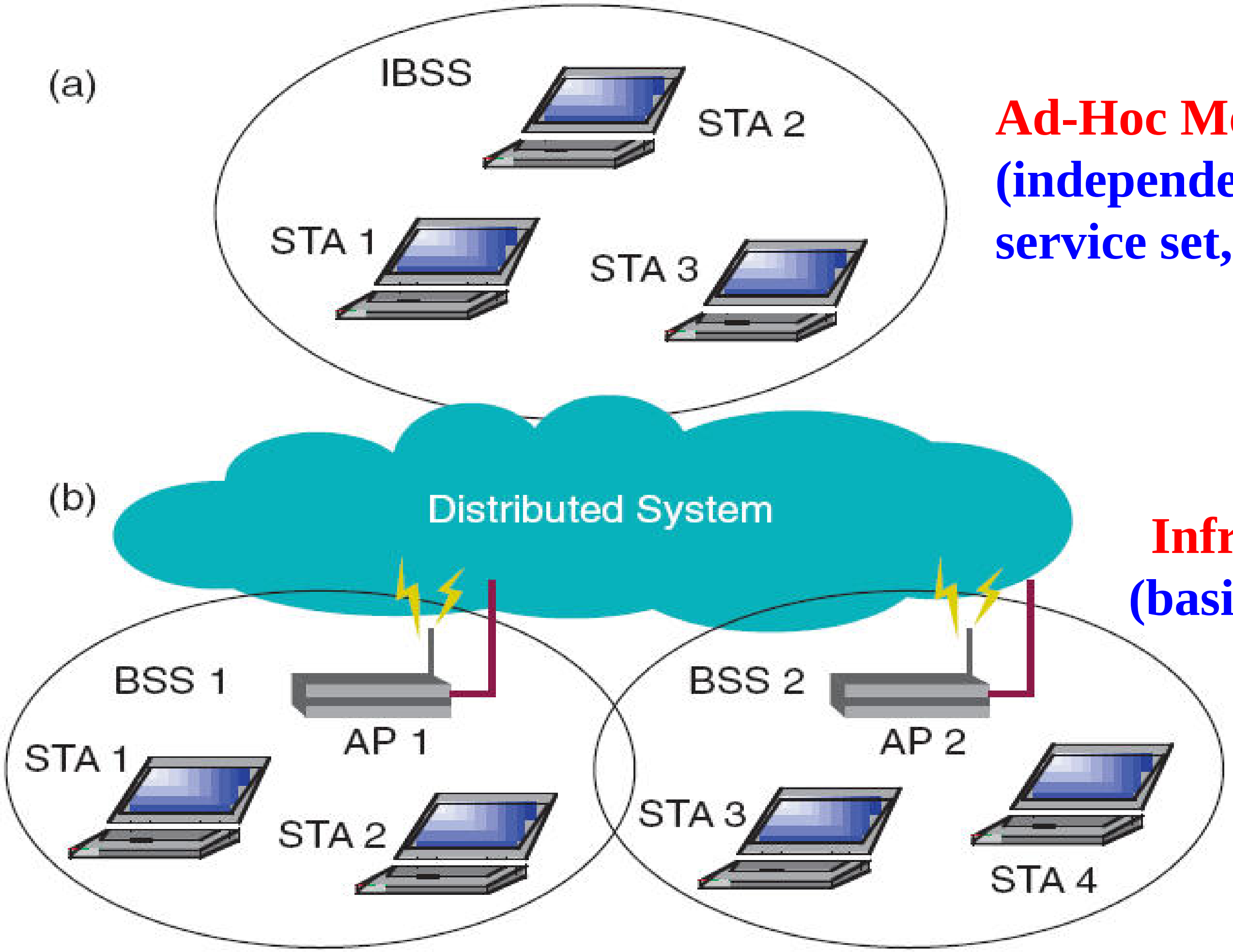
[Alamouti, 2007]

Perfect Synergy of WLAN/Wi-Fi and WiMAX



Are they ready for Multimedia Networking?

Ad-Hoc & Infrastructure Modes of 802.11 WLAN

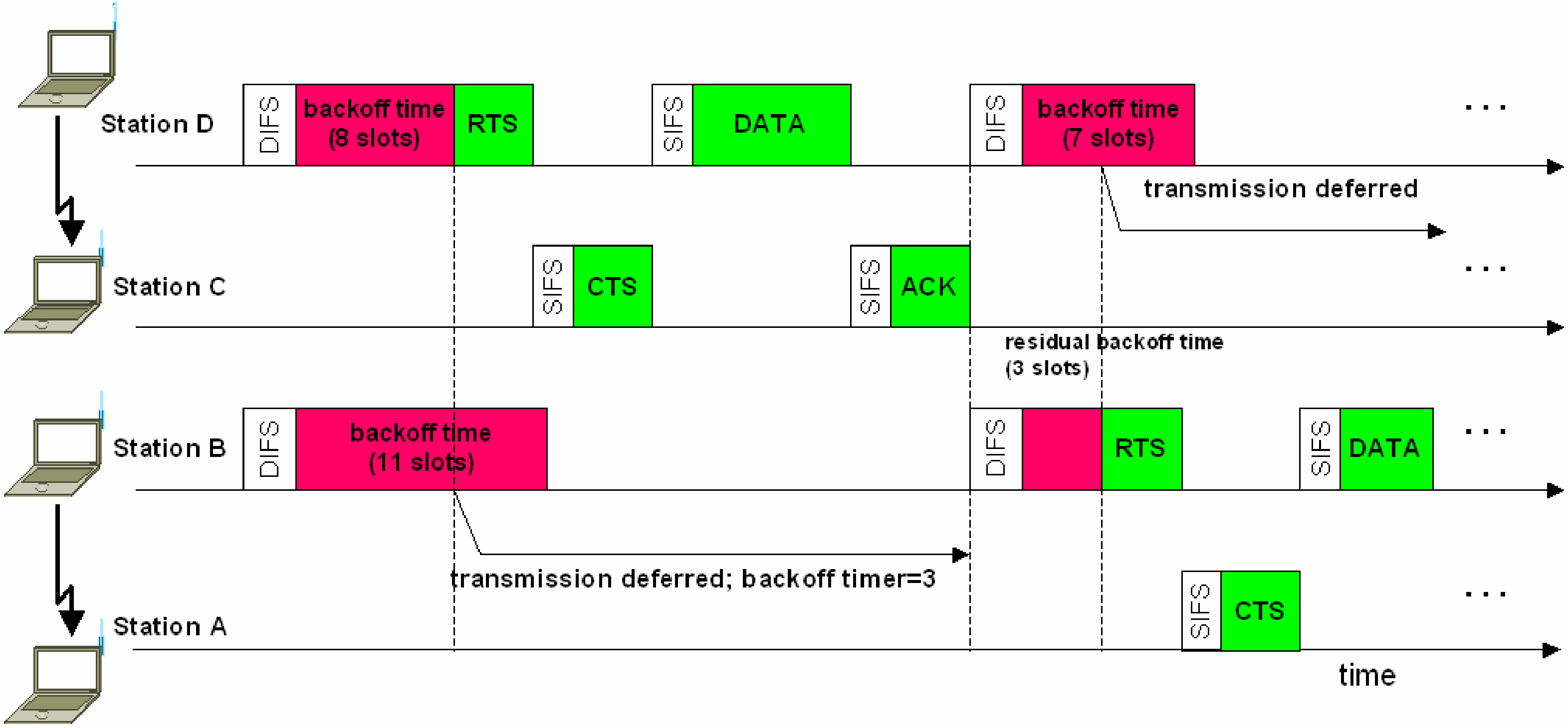


Ad-Hoc Mode
(independent basic service set, IBSS)

Infrastructure Mode
(basic service set, BSS)

CSMA/CA MAC Access

- A backoff scheme (combined with interframe spacing, IFS) for multiple access contention.



$$backoff\_time = rand[0; CW - 1] \times slot\_time = rand[0; CW_{\min} \times 2^n - 1] \times slot\_time$$

Link/Rate Adaptation in Multirate 802.11 WLAN

- IEEE 802.11 support multiple transmission rates, depending on the underlying channel condition, e.g., 802.11b: 11, 5.5, 2, 1 Mbps
- Techniques for link/rate adaptation:
  - AutoRate Fallback (ARF): consecutive failure/success
  - Receiver-based AutoRate (RBAR): RTS/CTS carrying
  - MiSer: a table-look-up for optimal rate-power combination
  - Goodput Rate Selection: ratio of the expected delivered data payload to the expected transmission time

Service Differentiation in 802.11 WLAN

- Varying DIFS and Backoff Time

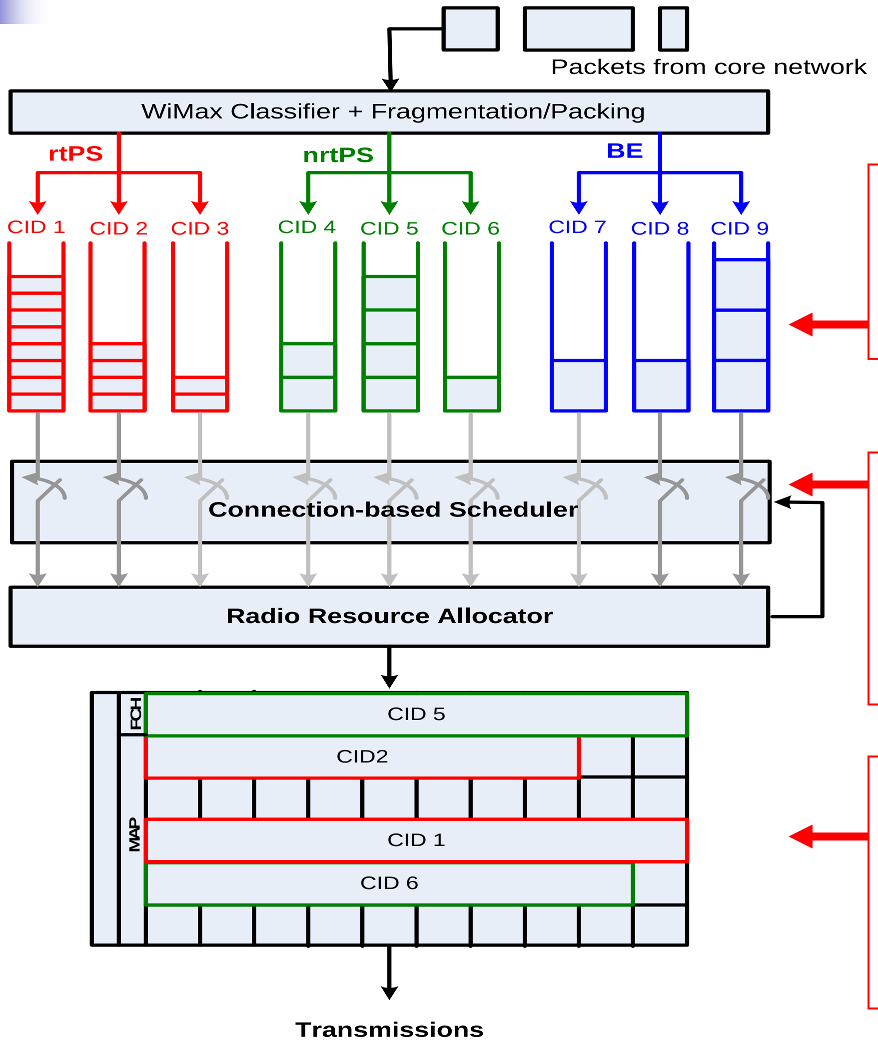
$$high\_priority: \quad backoff\_time = \frac{1}{2} rand[0; CW_{\min} \times 2^n) \times slot\_time$$

$$low\_priority: \quad backoff\_time = \frac{1}{2} CW \times 2^n \times slot\_time + \frac{1}{2} rand[0; CW_{\min} \times 2^n) \times slot\_time$$

- Limiting Maximum Frame Length: fragmentation
- Varying Initial Contention Window Size: CW_{min}
- **802.11e:** Enhanced Distributed Coordination Access

Access Categories	**AC_VO**	**AC_VI**	**AC_BE**	**AC_BK**
AIFS number	**2**	**2**	**3**	**7**
CWmin	**7**	**15**	**31**	**31**
CWmax	**15**	**31**	**1023**	**1023**

Centralized Scheduler & Resource Allocator of WiMAX



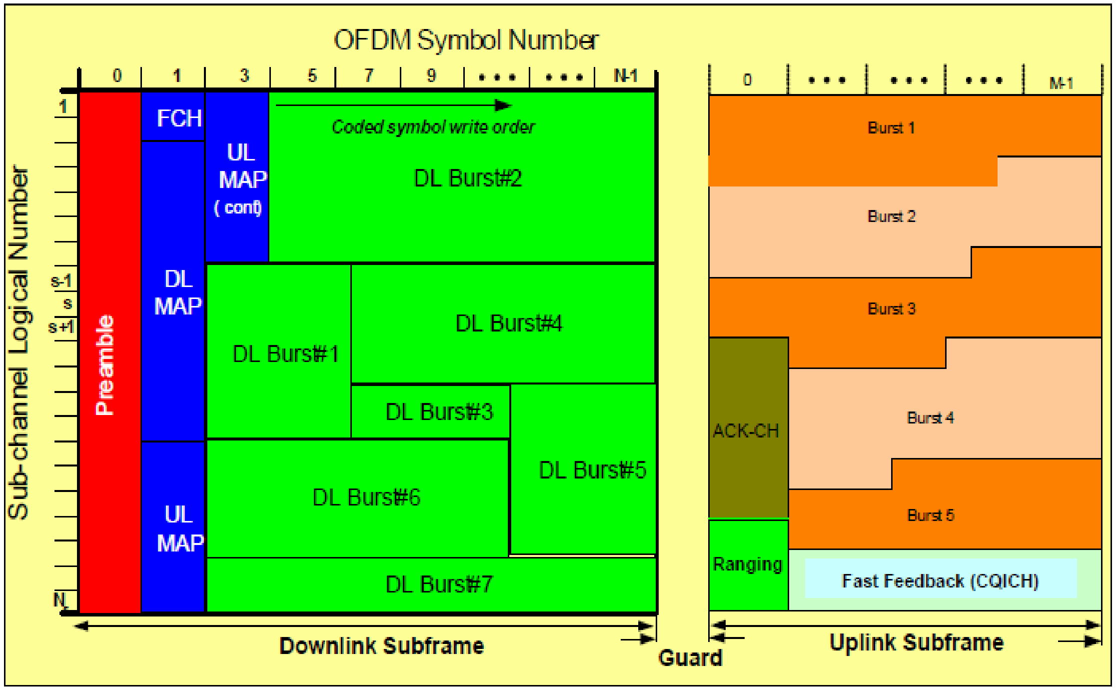
QoS Queues: each connection has a queue, packets of the same connection will be put into the same queue.

Packet/Connection Scheduler: decide which packet/connection and how many packets of this connection to be transmitted

Radio Resource Allocator: decide which subchannel frequencies and modulation & coding (MCS) for those scheduled packets

A WiMAX TDD Frame

- Partial Usage SubChannels (PUSC) for users with high velocity (low SNR)
- Band Adaptive Modulation & Coding (AMC) Subchannels for users with low velocity (high SNR)



Subscribers' Scheduling and radio Resource Allocation mechanisms are not specified in WiMAX standard

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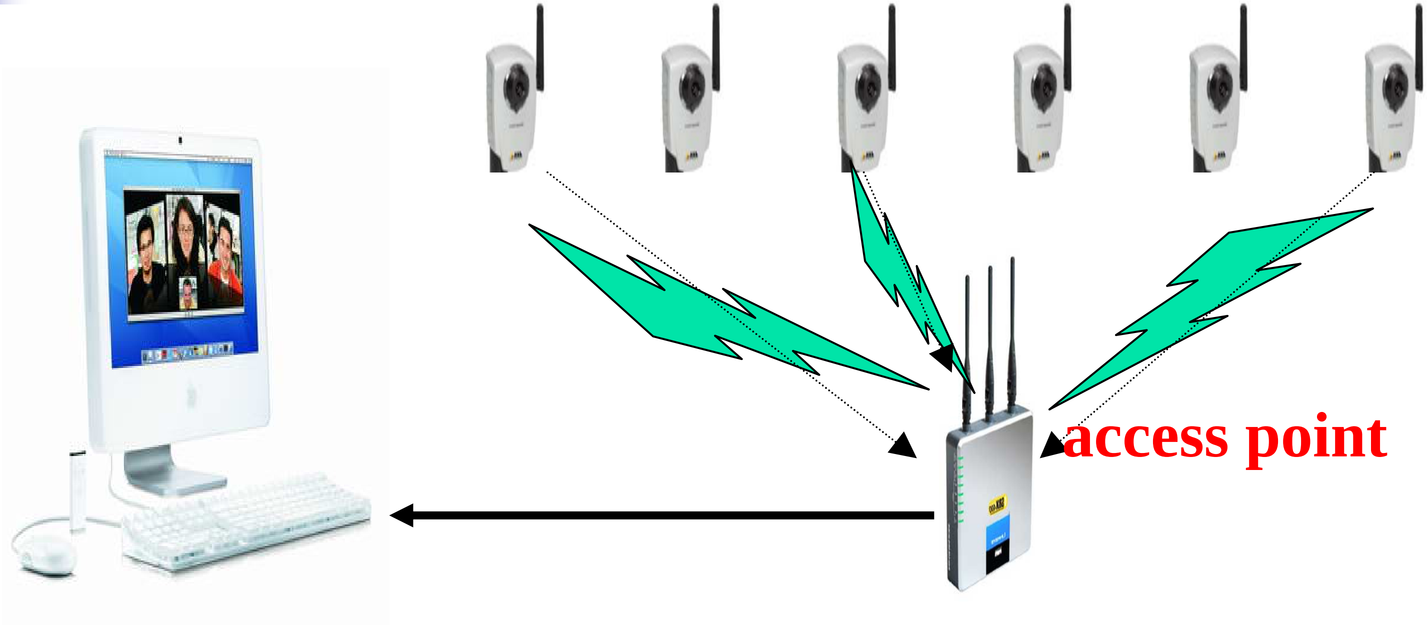
Serving Multiple Video Streams in A WLAN

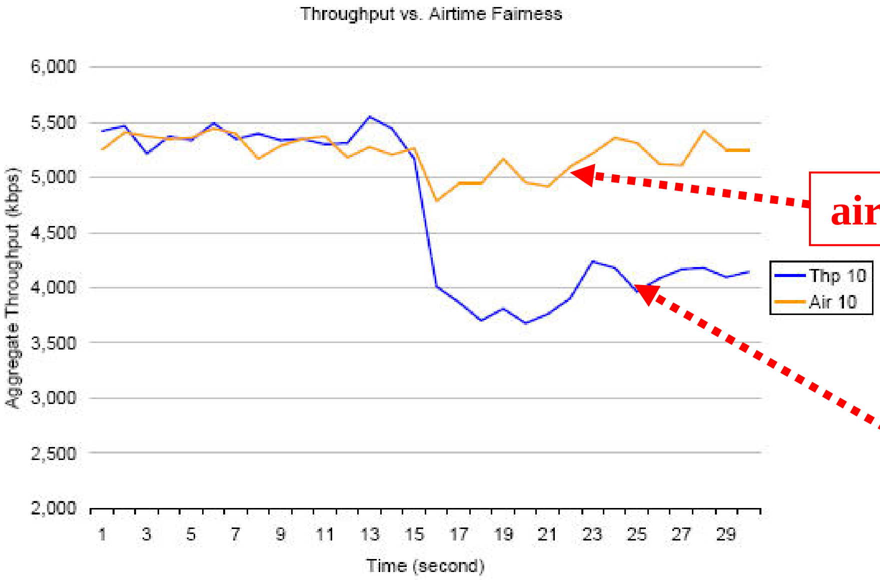


- In wireless home entertainment
- In video surveillance
- In search and rescue (military usage)

Link Adaptation & WLAN Performance Anomaly

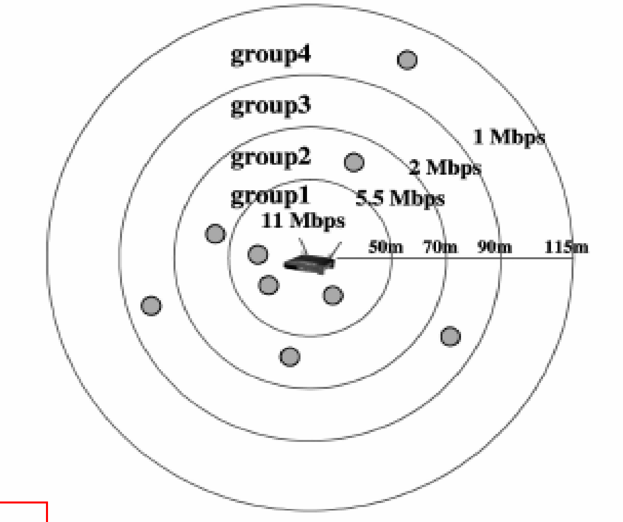
- The throughput of all hosts transmitting at the higher rate is degraded [Heusse03]

10x11M → 1x2M + 9x11M

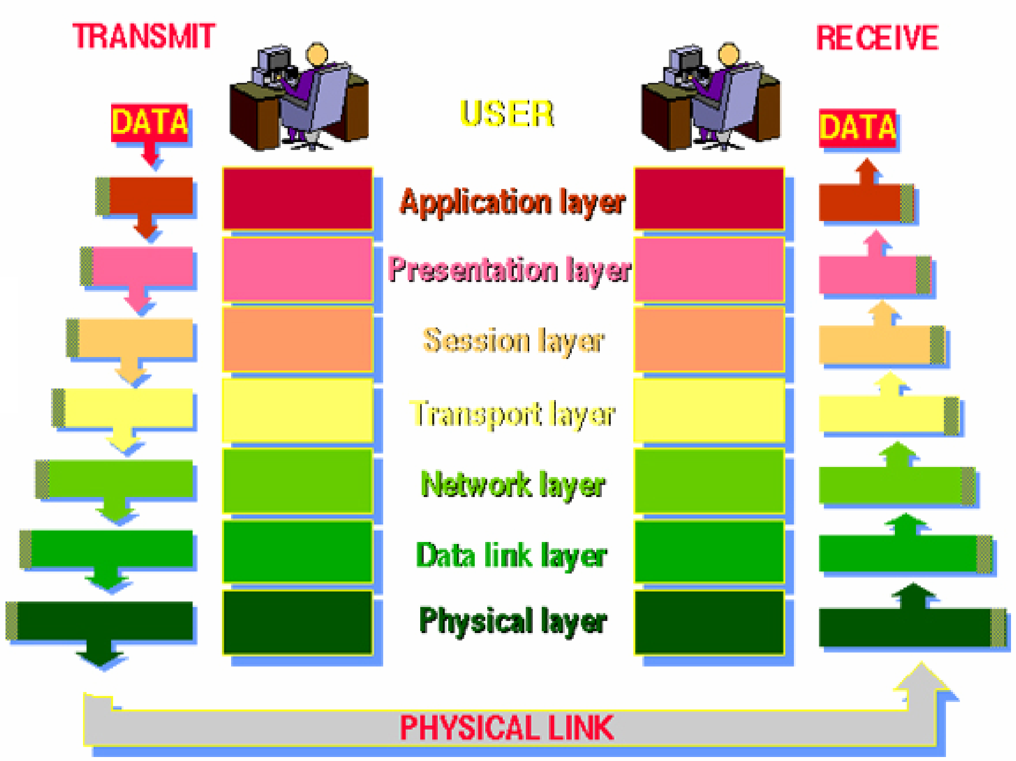


airtime fairness

throughput fairness



Cross Layer Solution?



Control Flow ↓

Timescales (sec)

1-10

0.01-0.1

0.001 – 0.01

0.0001 – 0.001

Call for a “distributed” control algorithm for airtime fairness that combines slow APP layer and fast MAC/PHY layer control loops

The Distributed Cross Layer Congestion Control (CLC)

PLR > 5% ⇨ Go lower rate

PLR < 3% for 3 sec ⇨ Go higher rate

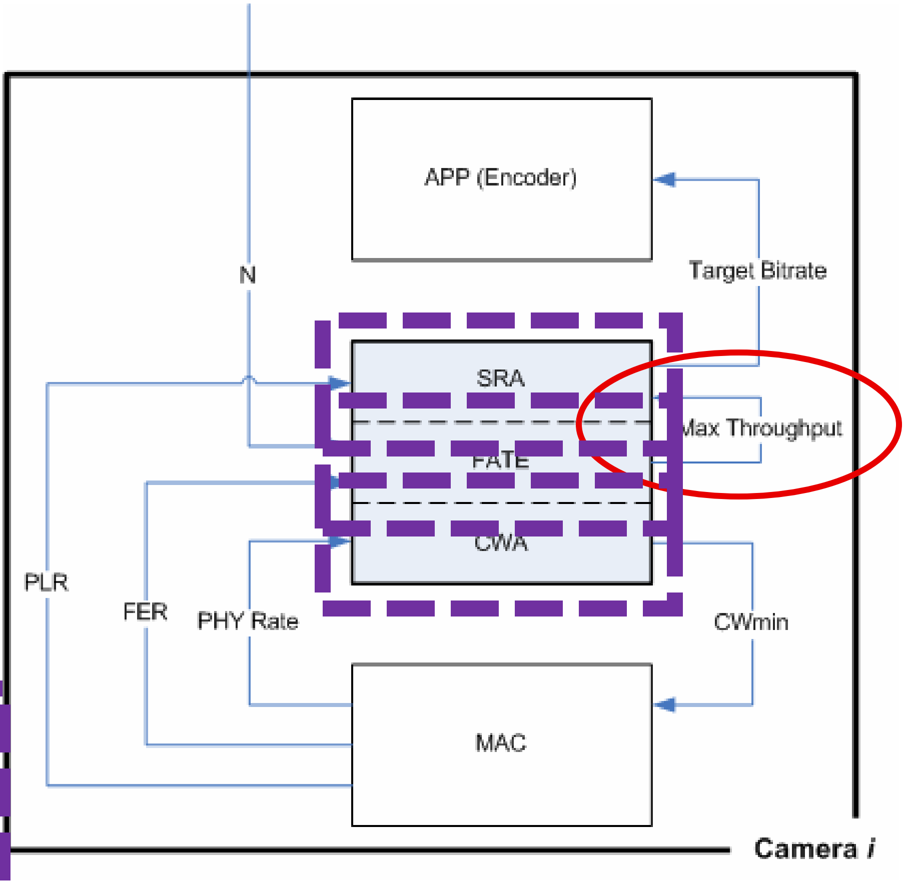
And within Max Throughput

Fair share of airtime x (1-FER)

$$G_e^i \approx \frac{1}{N} \cdot G_{MAX}^i \cdot (1 - p_f^i)$$

Higher data rate ⇨ Smaller contention window

$$r_i \cdot CW_{\min}^i = r_j \cdot CW_{\min}^j = const. \quad \forall i, j$$

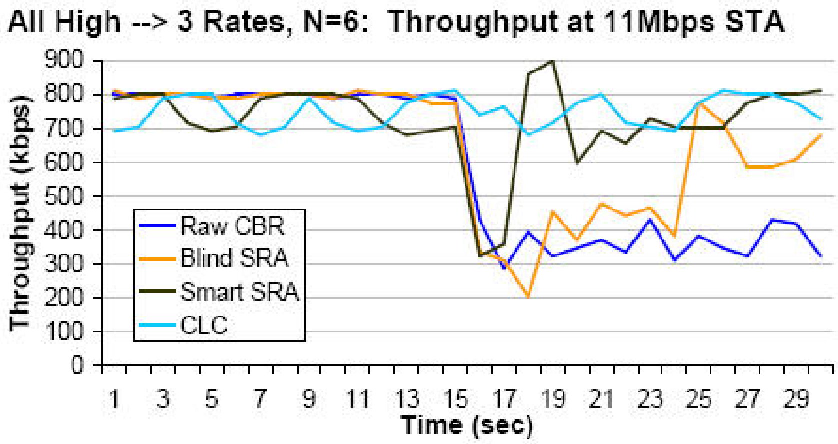


Experimental Evaluation

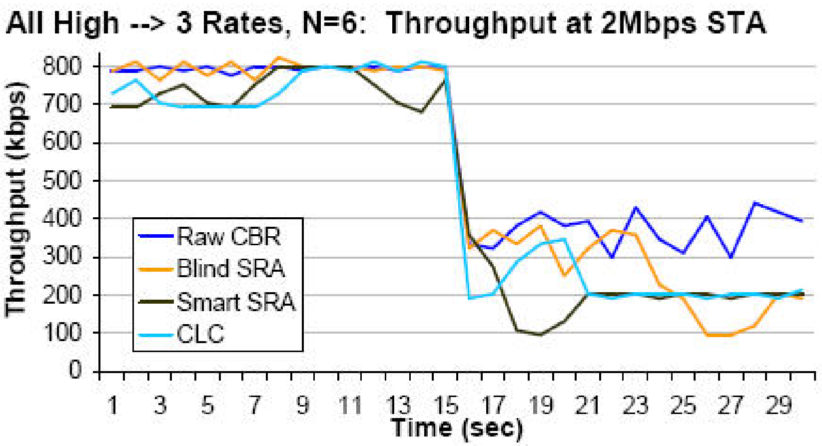
- Family of algorithms of increasing complexity
  - Simulation (ns2)
  - Real implementation
    - Axis 207w 802.11b/g cameras
    - Siemens AP2630 802.11b/g
  - Throughput, packet loss, PSNR in various dynamic scenarios with 4-10 cameras/sources
  - MPEG-4 video (100-800 Kbps)
  - Packet sniffing and statistics from custom Airopeek extension

ns2 Simulation Performance

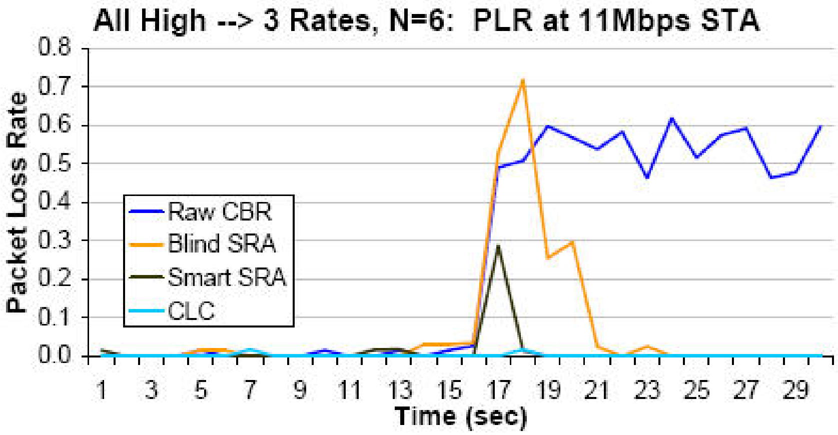
Three Rates in 6 STAs:
(11 11 5.5 5.5 2 2)
Video: 100-800 Kbps



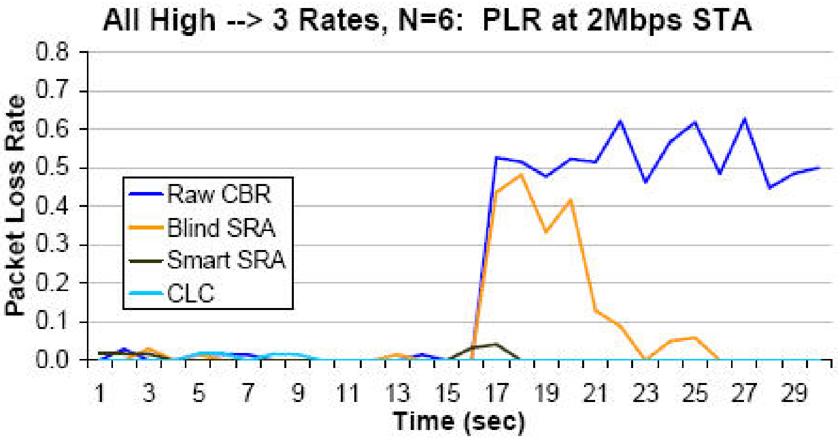
(a) 11 Mbps STA Throughput



(b) 2 Mbps STA Throughput



(c) 11 Mbps STA PLR

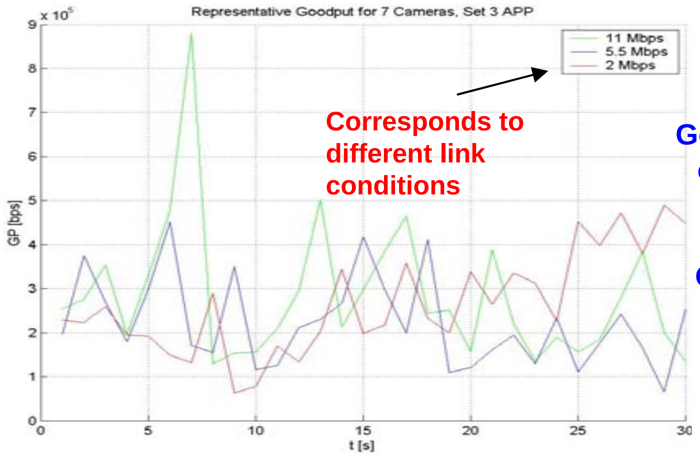


(d) 2 Mbps STA PLR

Real Implementation: Test 7 Cameras

CLC Off

CLC On

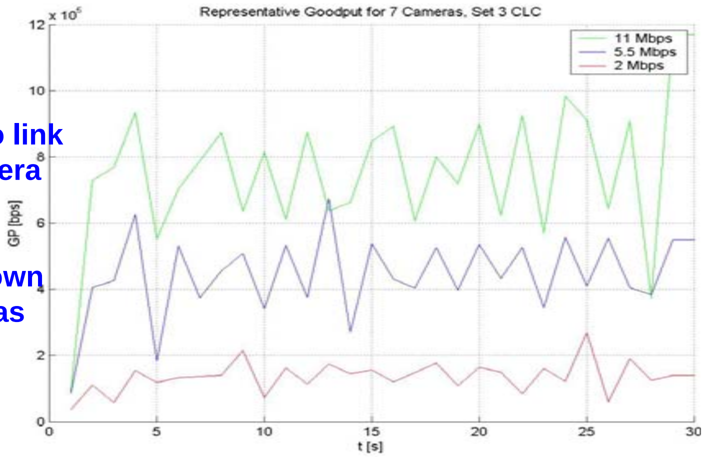


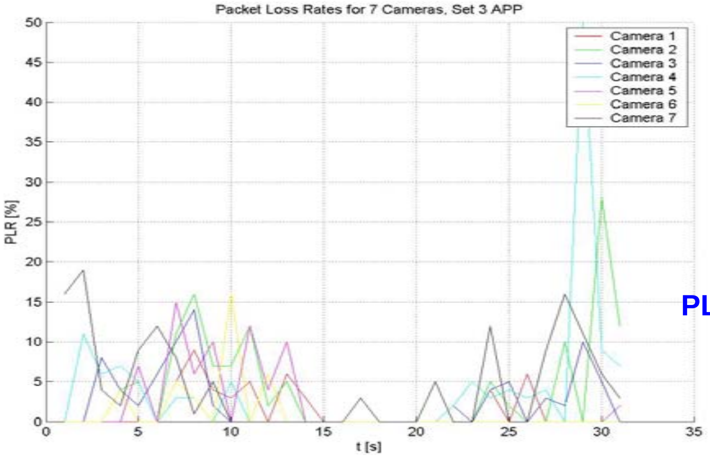
Corresponds to different link conditions

Goodput proportional to link condition of each camera

FAIRNESS

One bad link brings down goodput of all cameras

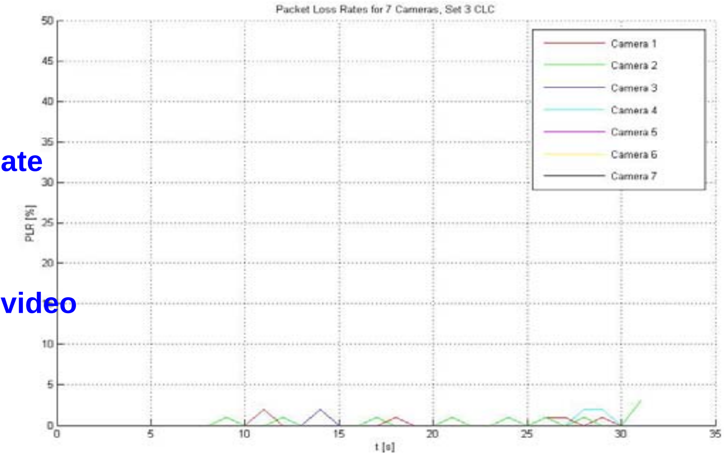




~ 0% Packet Loss Rate

QUALITY

PLR unacceptable for video streaming



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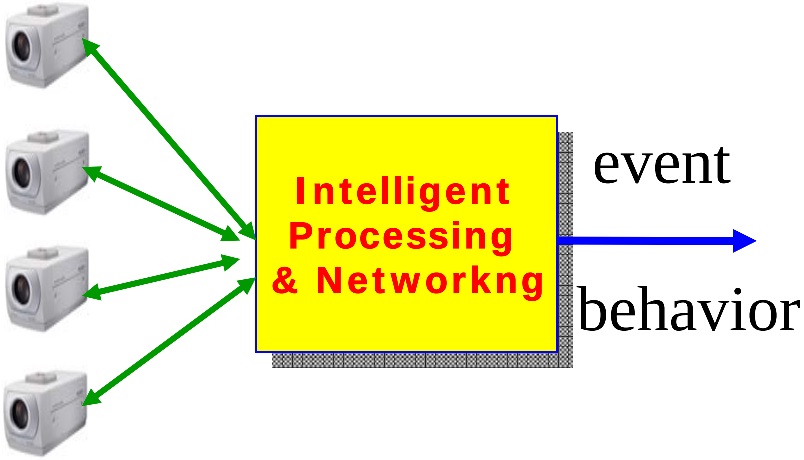
Distributed Wireless Ad Hoc Camera Networks



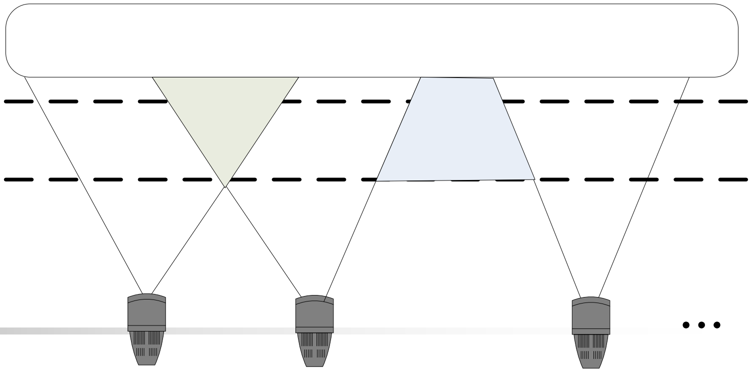
Intelligent Processing & Networkng

event

behavior

- More than 600,000 video camera deployed in London
- One human operator: 6-10 camera, 1-2 hours vigilance span
- Apply intelligence (a predefined set of rules) strategically to an array of networked video cameras, for security surveillance and health care monitoring

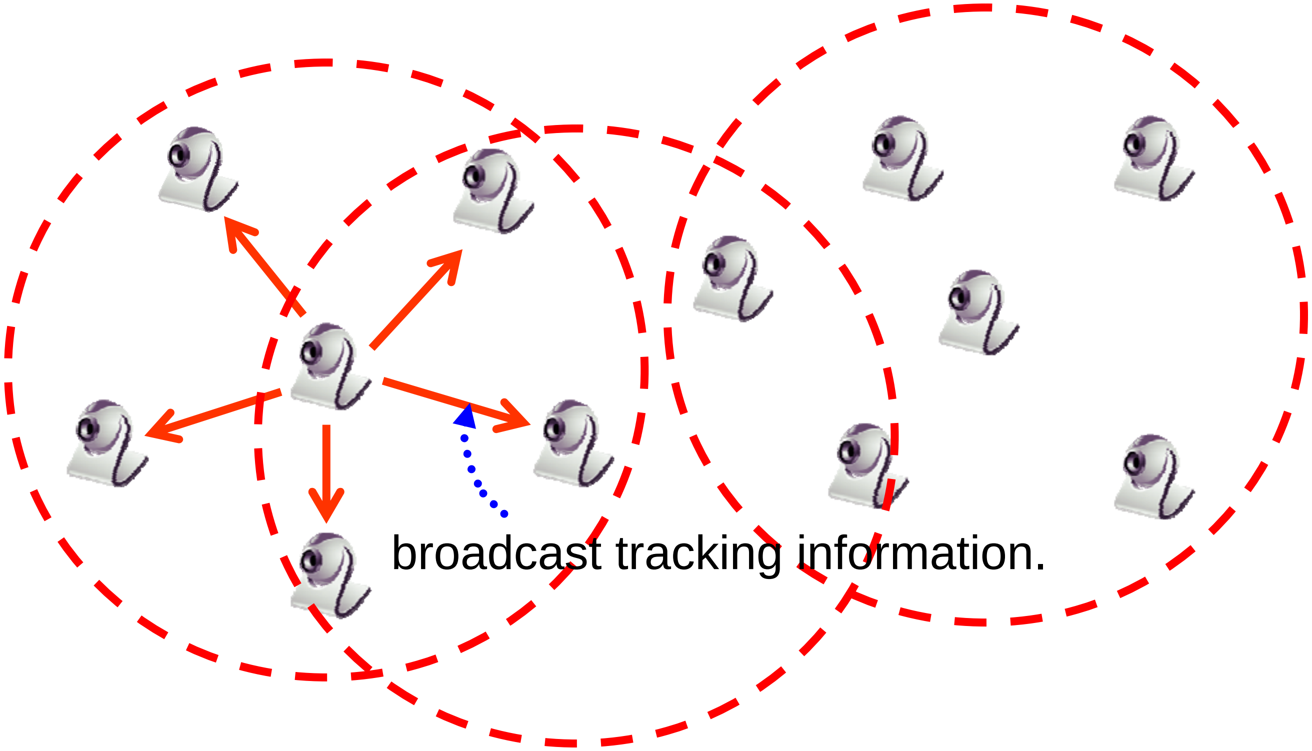
Tracking Across Distributed Camera Networks (DCNs)



Overlapping Field of View

Non-Overlapping Field of View

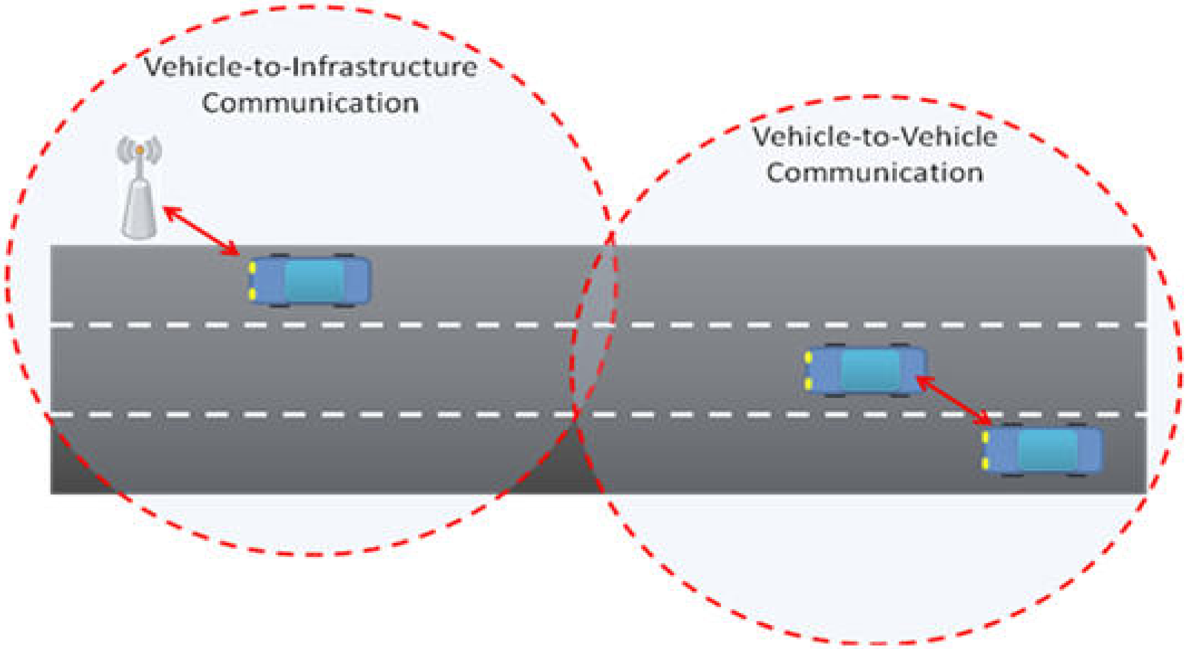
One-Hop or Multi-Hop Broadcasting



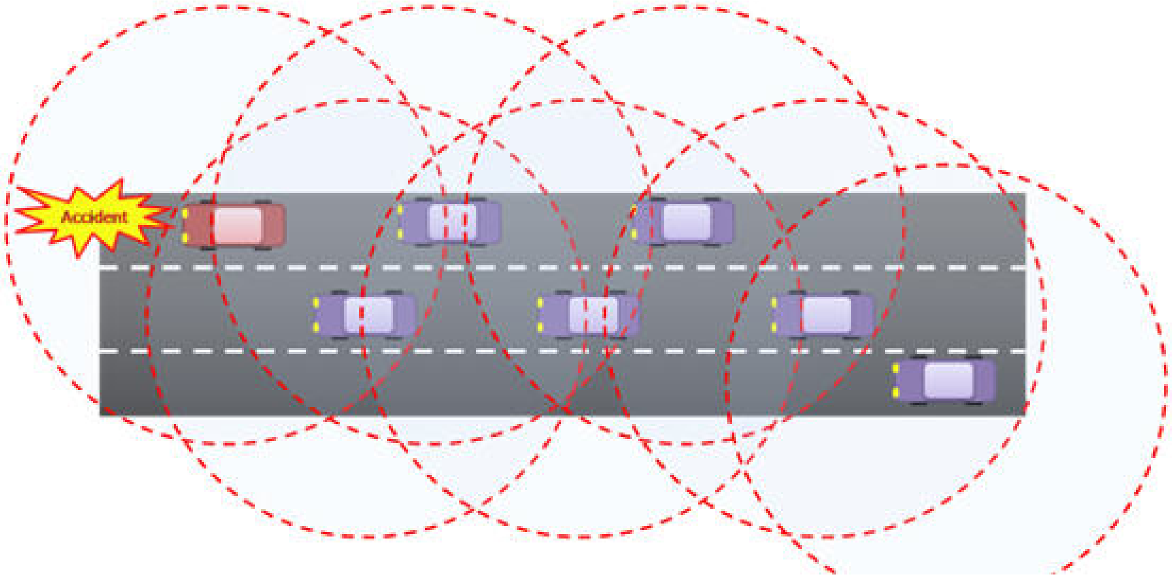
broadcast tracking information.

Broadcast Storm Problem

Application to Vehicular Ad-Hoc Networks (VANETs)

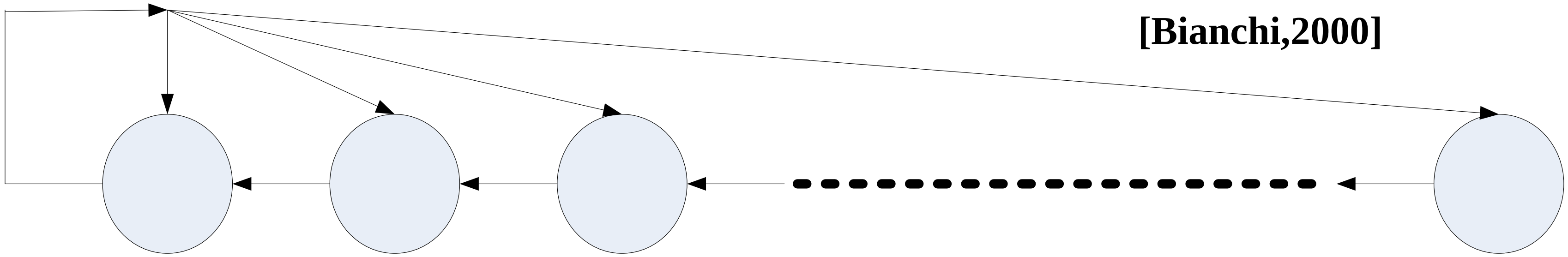


emergency or location aware video



Modeling Backoff Mechanism using 802.11

- When broadcasting, no *RTS/CTS*, no *ACK*, no retransmission, no exponential backoff, and a fixed contention window, *W=CW*.



[Bianchi,2000]

$$p\{b(t)=k\} = p\{b(t-1)=k+1\} + \frac{p\{b(t-1)=0\}}{W}, \qquad k<W-1$$

$$p\{b(t)=W-1\} = \frac{1}{W}\, p\{b(t-1)=0\}, \qquad k=W-1$$

$$\lim_{t\to\infty} p\{b(t)=k\} = p_k = \frac{2(W-k)}{W(W+1)},$$

$$p_0 = \frac{2}{W+1}\ \text{(transmission prob)}$$

$$1/W$$

Modeling the Dynamics of Multiple Nodes

- In case of "*n*" competing nodes and "n_t" transmitting nodes (assume they are independent)

$$\text{no transmission}: p_x(n) = p\{n_t = 0\} = (1 - p_0)^n$$

$$\text{at least one transmission}: p_t(n) = p\{n_t \geq 1\} = 1 - (1 - p_0)^n$$

$$\text{exactly one transmisison}: p_s(n) = p\{n_t = 1\} = np_0(1 - p_0)^{n-1}$$

$$\text{node collision}: p_c(n) = p\{n_t \geq 2\} = 1 - p_s(n) - p_x(n)$$

Metrics for Performance Evaluation

- Packet Delivery Ratio (PDR)

$$PDR = \frac{\text{Average Number of Packets Successfully Delivered}}{\text{Average Number of Packets Delivered}} = \frac{p\{n_t = 1\}}{\sum_{i=1}^{n} i \cdot p\{n_t = i\}}$$

$$= \frac{\binom{n}{1} \cdot p_0 \cdot (1 - p_0)^{n-1}}{n \cdot p_0} = \frac{n \cdot p_0 \cdot (1 - p_0)^{n-1}}{n \cdot p_0} = (1 - p_0)^{n-1}$$

- Normalized Throughput S' (assume $T_s = T_c = T_\sigma \cdot \sigma$)

$$S^{'} = \frac{L_{avg}}{C \cdot T_{avg}} = \frac{1}{C} S, \ (S = \text{throughput}, C = \text{channel capacity})$$

$$\text{where} \quad T_{avg} = p\{n_t = 0\} \cdot \sigma + p\{n_t = 1\} \cdot T_s + p\{n_t > 1\} \cdot T_c$$

$$\text{and} \ L_{avg} = p\{n_t = 1\} \cdot L_{payload\_bytes} \cdot 8$$

Throughput Maximization

- Optimal contention window size, *W** [Bianchi,2003]

$$\text{Let } \frac{dS'}{dp_0} = 0 \Rightarrow (1-p_0)^n - T_\sigma\{np_0 - [1-(1-p_0)]\} = 0$$

$$\text{Assume } W >> n > 1, \text{ then } (1-p_0)^n \approx 1 - np_0 + \frac{n(n-1)}{2} p_0^2$$

$$p_0^* \approx \frac{1}{n}\sqrt{\frac{2}{T_\sigma}} \Rightarrow W^* \approx n\sqrt{2T_\sigma} \leftarrow \text{(average packet duration in slots)}$$

- Based on IEEE STD 802.11-2007, content window size *W* is hardwired in PHY layer, even though specified in 802.11e MAC and many wireless QoS solutions.
- Reliably estimating the umber of competing nodes, *n*, is another challenging issue.

Adjust Transmission Prob. With Fixed Contention Window?

- If channel idle probability is high, then deliver more.
  - Pidle ↑ ➔ $P_0(n)$ ↑
  - $P_0(n)$: transmission probability of individual node
- If channel idel probability is low, then deliver less.
  - Pidle ↓ ➔ $P_0(n)$ ↓
- iPro (Idle Probability based broadcasting)
  - P_0 (n)= Pidle * p_0

$$\tilde{P}_{idle}(t) = (1 - \frac{\Delta t}{T_0}) \cdot \tilde{P}_{idle}(t - \Delta t) + \frac{\Delta t}{T_0} \cdot b, \quad \text{where} b = \begin{cases} 0, & \text{if channelbusy.} \\ 1, & \text{if channelidle.} \end{cases}$$

iPro Scheme

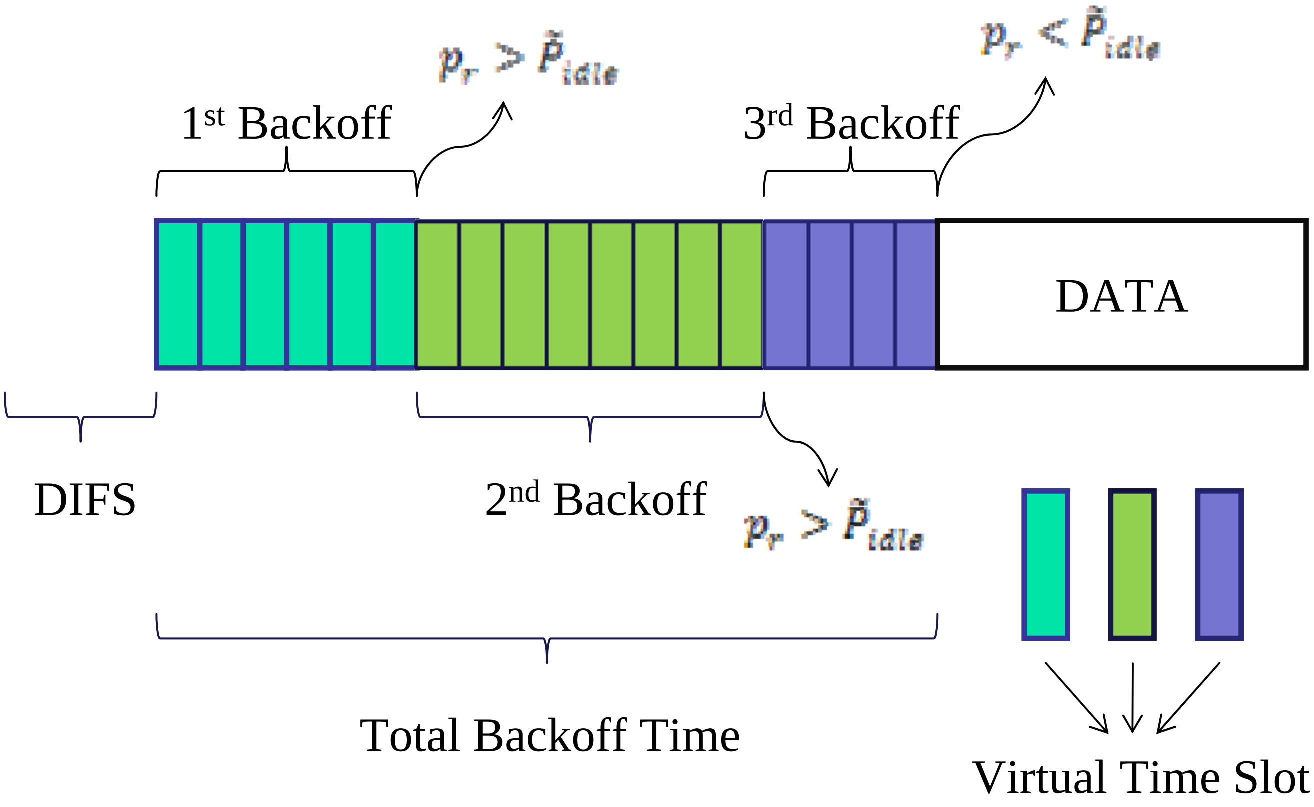
Periodically update channel idle probability $\tilde{P}_{idle}$

On Backoff timer expires:

    Generate a random number p_r over [0,1]

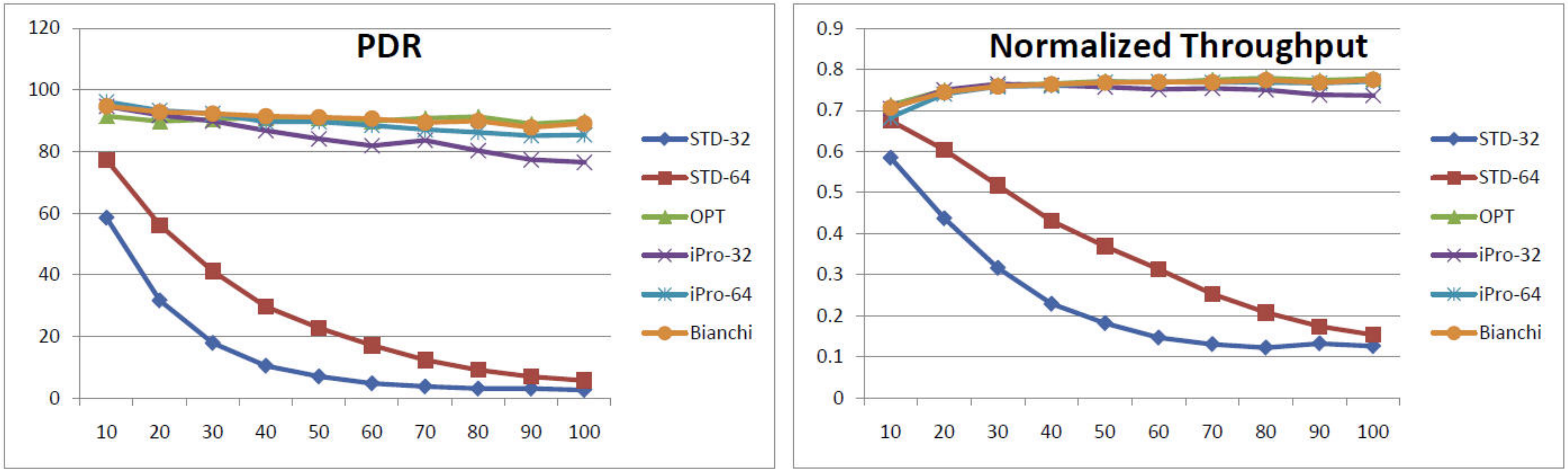
    if $p_r < \tilde{P}_{idle}$ transmit the packet

    else entering re-backoff



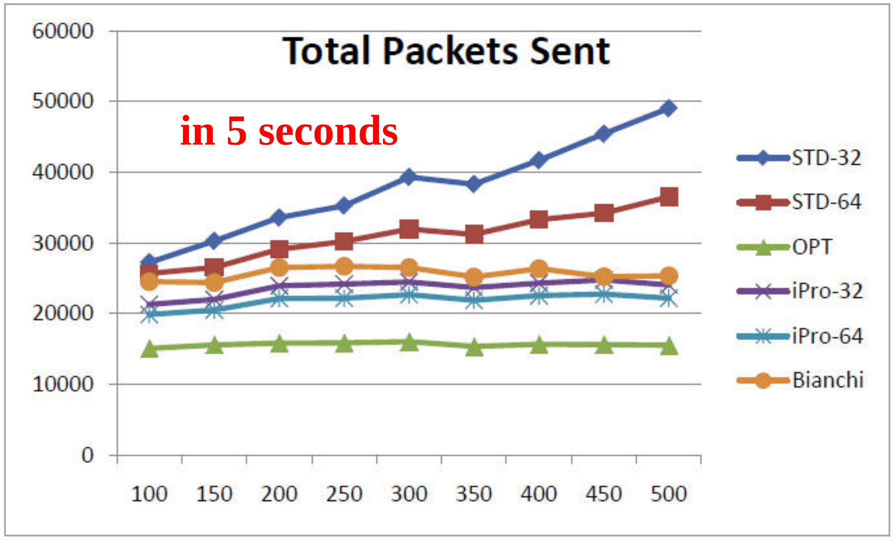
Single Hop Simulations

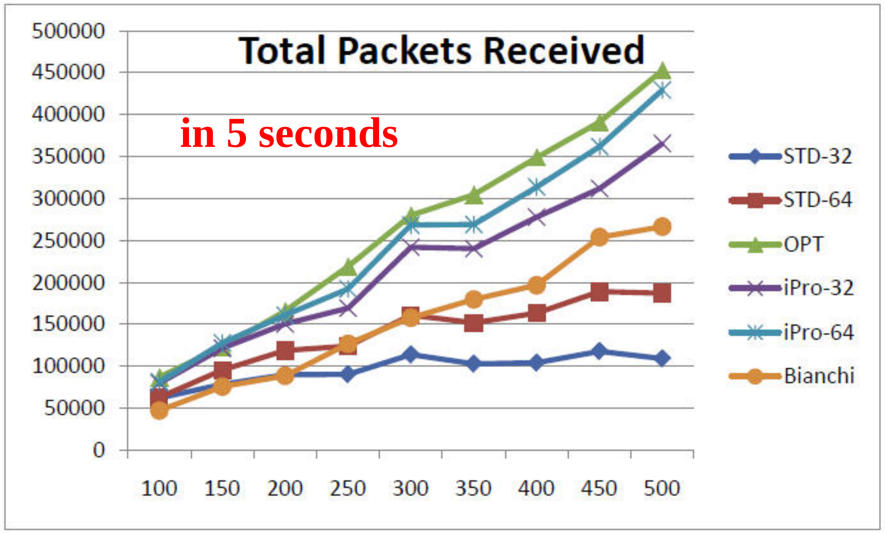
- Network topology: *50x50 m^2*
- Transmission Range: *100 m*
- Carrier Sense Range: *250 m*
- Data rate: 1Mbps (802.11b), capture effect is disabled.



Multi-Hop Simulations

- Network topology: *500x500 m^2*
- Transmission Range: *100 m*
- Carrier Sense Range: *250 m*
- Data rate: 1Mbps (802.11b), (hidden node problems).





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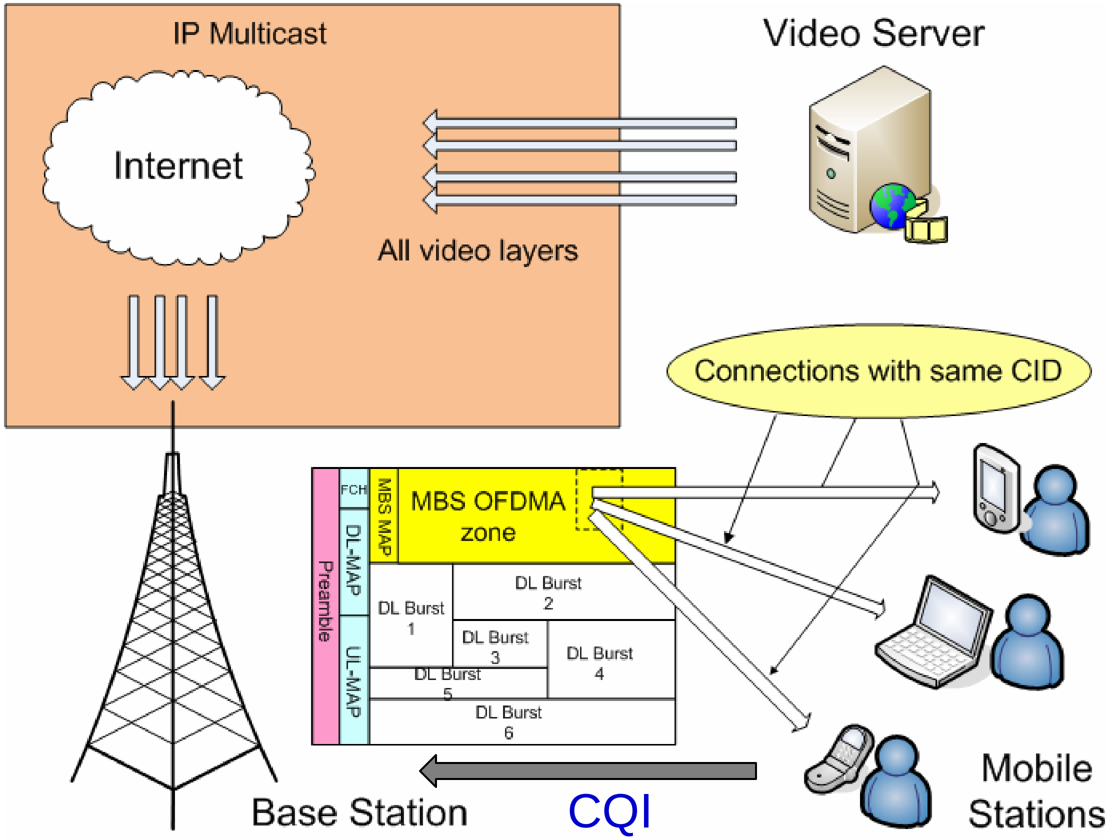
An End-to-End Scalable IPTV WiMAX Multicasting



CQI: channel quality indicator

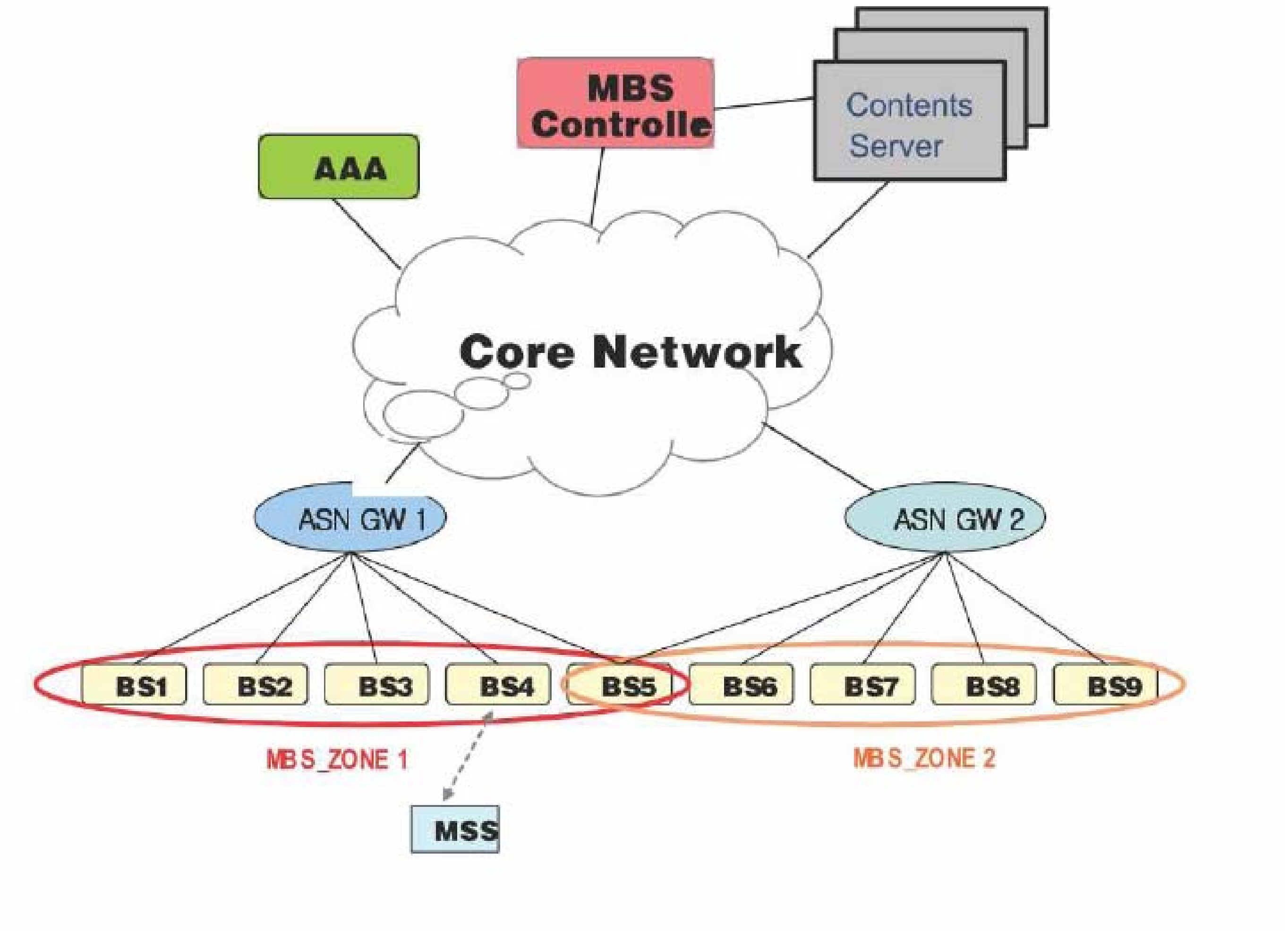
MCS: modulation and coding scheme

CID: connection id

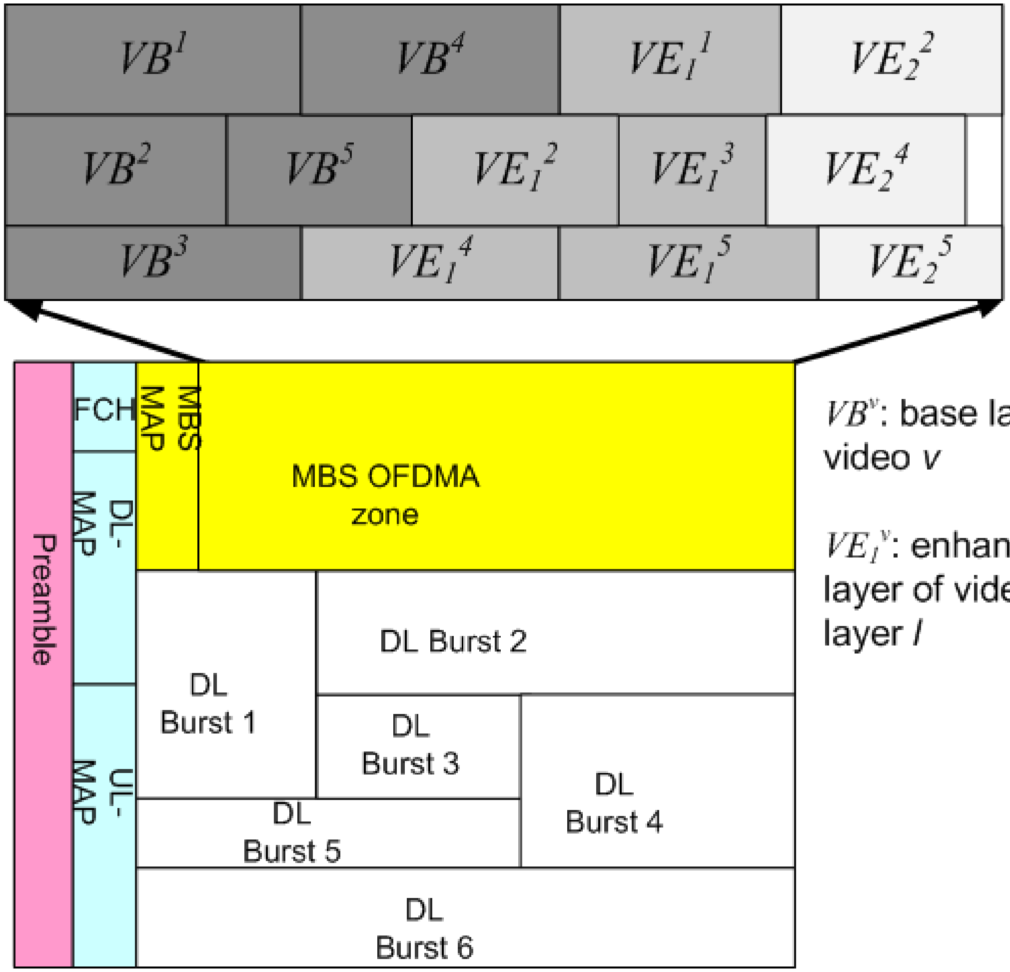
MBS: multicast and broadcast service

Video Layer → Multicast group → WiMAX Connection

MBS Zone with Multi-BSs

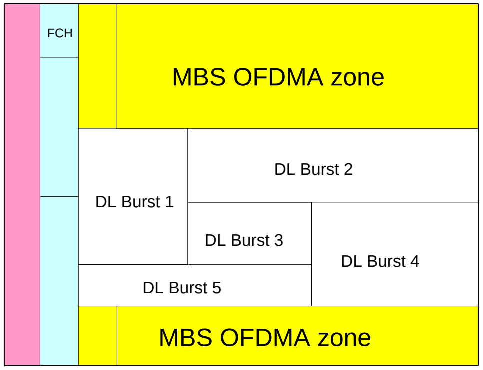


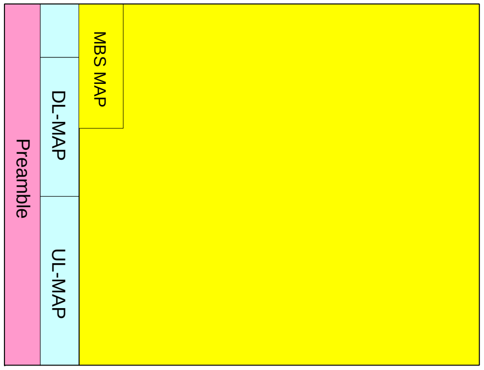
Mapping SVC Layers in an MBS Zone



VB^v: base layer of video *v*

VE_l^v: enhancement layer of video *v*, layer *l*



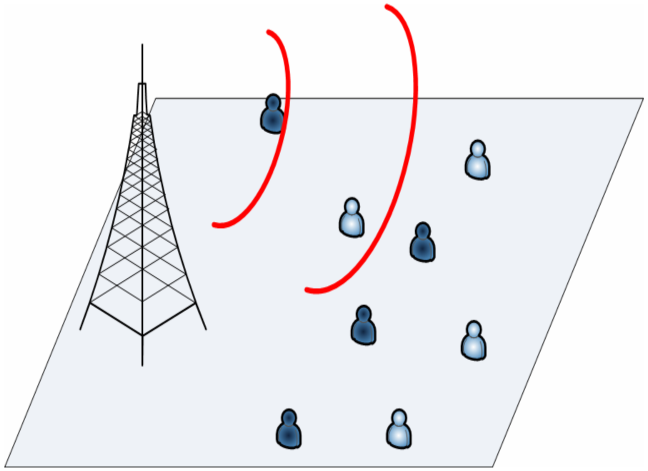


MCS Selections in WiMAX

Modulation	Coding Rate	Required Receiver SNR (dB)	Normalized OFDMA Slot Capacity
QPSK	1/2	5	1
	3/4	8	1.5
16-QAM	1/2	10.5	2
	3/4	14	3
64-QAM	1/2	16	3
	2/3	18	4
	3/4	20	4.5

Opportunistic Multicasting Scheduling

- For a given set of subscribers
  - Schedule a subset of subscribers in every transmission opportunity
  - Channel quality (CQI) as criteria
  - Adaptive (MCS) as tools
- Take advantage of
  - Temporal channel quality fluctuation
  - User diversity
- Result in
  - Higher throughput (lower resource consumption)
  - Higher total system utility



Base Layers for Everyone

- ***max min*** (effective, bottleneck) frame receiving $\overline{Q_i^k}, \forall i \in \mathrm{U}$

$$\overline{Q_i^k} = \begin{cases} (1-\frac{1}{tc})\times\overline{Q_i^{k-1}} + \frac{1}{tc}\times I(m^{k-1}, q_i^{k-1}), & k>1 \\ 1, & k=1. \end{cases}$$

- Adapting MCS subject to minimize slot consumptions

$$K^b = \begin{cases} \left\lfloor N \times \min_{i\in\mathrm{U}}\left\{\overline{Q_i^{(b-1)N}}\right\} \times fm \right\rfloor, & b>1; \\ \left\lfloor N/2 \right\rfloor, & b=1. \end{cases}$$

$$r^b = \frac{K^b}{N}.$$

$$S^k = \left\lceil \frac{R}{c(m^k)} \right\rceil, \quad m^k \in \mathrm{M}$$

$$m^k = \arg\max_{m\in\mathrm{M}}\left\{c(m)\times I(m, q_{\tilde{i}}^k) : \tilde{i} = \arg\min_{i\in\mathrm{U}}\left\{\overline{Q_i^k}\right\}\right\}.$$

Enhancement Layers Subset Selections

- Maximize total system utility functions
  - Corresponding to (QoE) quality gain of each layer
  - Imply to maximize utility gain per unit of resource
- Jointly consider scheduling and resource allocation
- Subject to
  - System-wide gain
  - Available resource
  - Layer dependency

$$\max \sum_{v} \sum_{l} u_{v,l} \cdot \left| N_{v,l} \right|$$

subject to $\sum_{v} \sum_{l} S_{v,l}(N_v) \le B$

$$G_{v,l}\left(i\right) = \overline{Q}^{k}_{i,v,l} \cdot \left| \left\{ j : \overline{Q}^{k}_{j,v,l} \ge \overline{Q}^{k}_{i,v,l},\ j \in \mathbf{N}_v \right\} \right|$$

$$G_{v,l} = u_{v,l} \cdot \min \left\{ \overline{Q}^{k}_{v,l} \right\} \cdot \left| \mathbf{N}_{v,l}(m^{k}_{v,l}) \right|$$

- Have to iterate resource allocation and scheduling

Simulation Setup

Parameters	Value
Operating frequency	2.5 GHz
Duplex	TDD
Channel bandwidth	10 MHz
Cell radius	1.4 km
BS Height	32 m
MS Height	1.5 m
BS Antenna Gain	15 dBi
MS Antenna Gain	-1 dBi
Antenna Pattern	70 ° (-3 dB) with 20 dB front-to-back ratio
MS Noise Figure	7 dB

Parameters	Value
Permutation mode	PUSC
FFT size	1024
Sub-carrier frequency spacing (f)	10.94 kHz
Useful Symbol time ($T_b = 1/f$)	91.4 μs
Guard time ($T_g = T_b/8$)	11.4 μs
OFDMA Symbol Duration ($T_s = T_b + T_g$)	102.9 μs
Frame duration (t_{fr})	5 ms
PUSC Mode	
Null sub-carriers	184
Pilot sub-carriers	120
Data sub-carriers	720
Number of sub-carriers per cluster	24 data+ 4 pilot
Number of clusters per slot	2

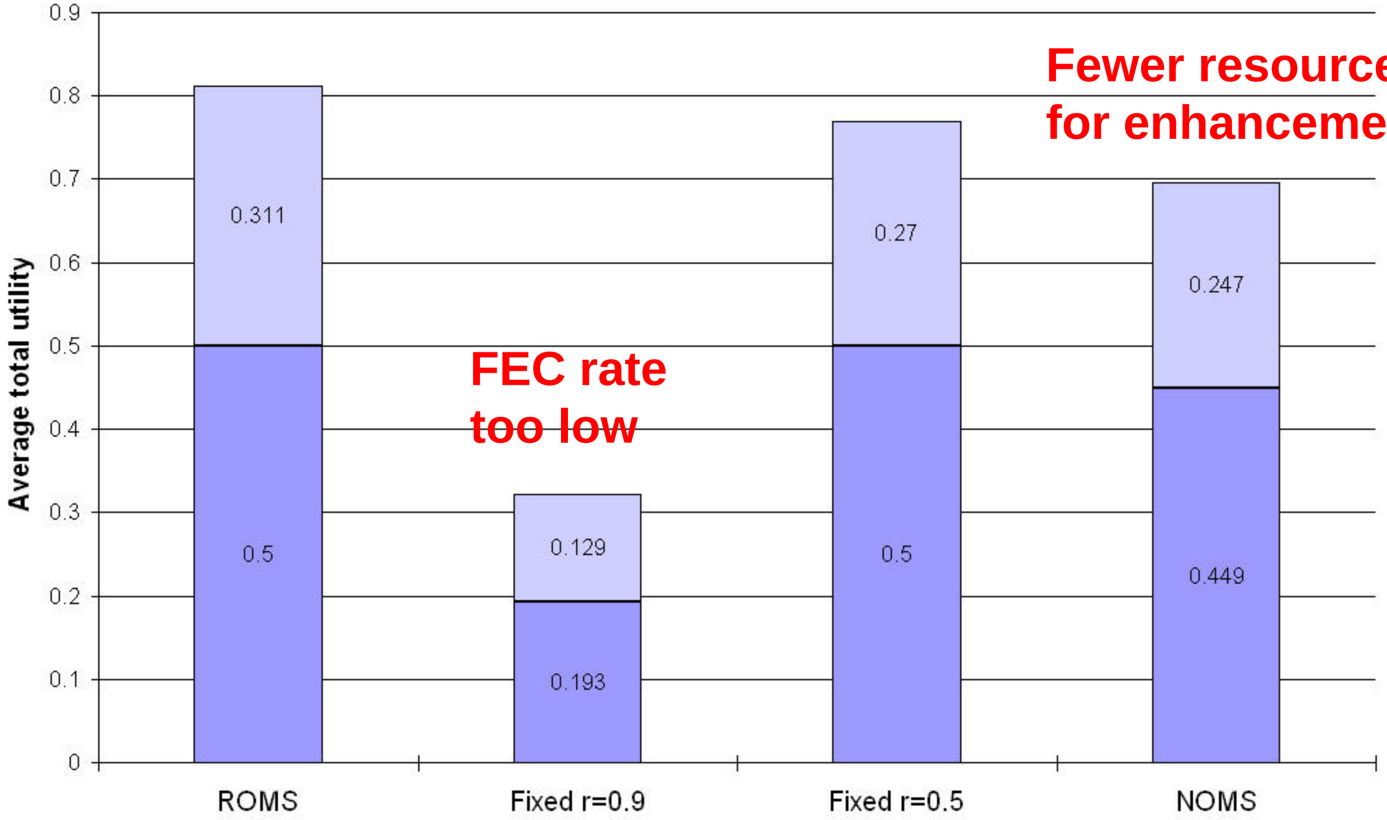
- IEEE 802.16e OFDMA PUSC mode
- COST 231 propagation loss model
- ITU Vehicular A power delay profile
- Mobile stations are uniformly distributed in the cell

Application Setup

- Pre-allocate 1/4 of total channel for multicast
- 3 videos with subscribers {100, 80, 40}
- 4 layers each with utility {0.5, 0.25, 0.15, 0.1}
- 250 Kbps each layer
- 200 frame FEC block size (about 1 sec)
- Schemes to compare:
  1) Proposed (adaptive *r*);
  2) fixed FEC at $r=09$;
  3) fixed FEC at $r=0.5$;
  4) non-opportunistic scheme (NOMS)

$$r^b = \frac{K^b}{N}.$$

Overall Performance



FEC rate too low

Fewer resource for enhancement

- Based layers can be received as long as enough FEC protection

Conclusion

- Future internet = content + service + management (interactive, ubiquitous, personalized, secure, aware)
- Video networking and IPTV are killer applications for the next generation wireless broadband
- Current wireless broadband standards are not ready for large scale practical video dissemination
- Three QoS top-down design examples (MediaNets)
    - Understand better the application & data
    - Decide which layers (time and spatial granularity) can be improved
    - Cross layers can be even more effective