



# Quality-of-Service for Multimedia Service over Wireless Networks

(User-centric/Media-specific approach)

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# Outline

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- Introduction
  - ◆ Why QoS is essential for multimedia services?
  - ◆ Why difficult to guarantee QoS over wireless network?
- Our current approaches
  - ◆ Cross network approach
    - End-to-end path virtualization over multiple heterogeneous wireless networks (with Mr. **Sang-Chun Han**)
  - ◆ Cross layer approaches
    - Urgency-based cross-layer routing and packet scheduling algorithm over mobile ad hoc network (with Mr. **Ki Jin An**)
- Concluding remarks

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- ◆ Why difficult to guarantee QoS over wireless network?

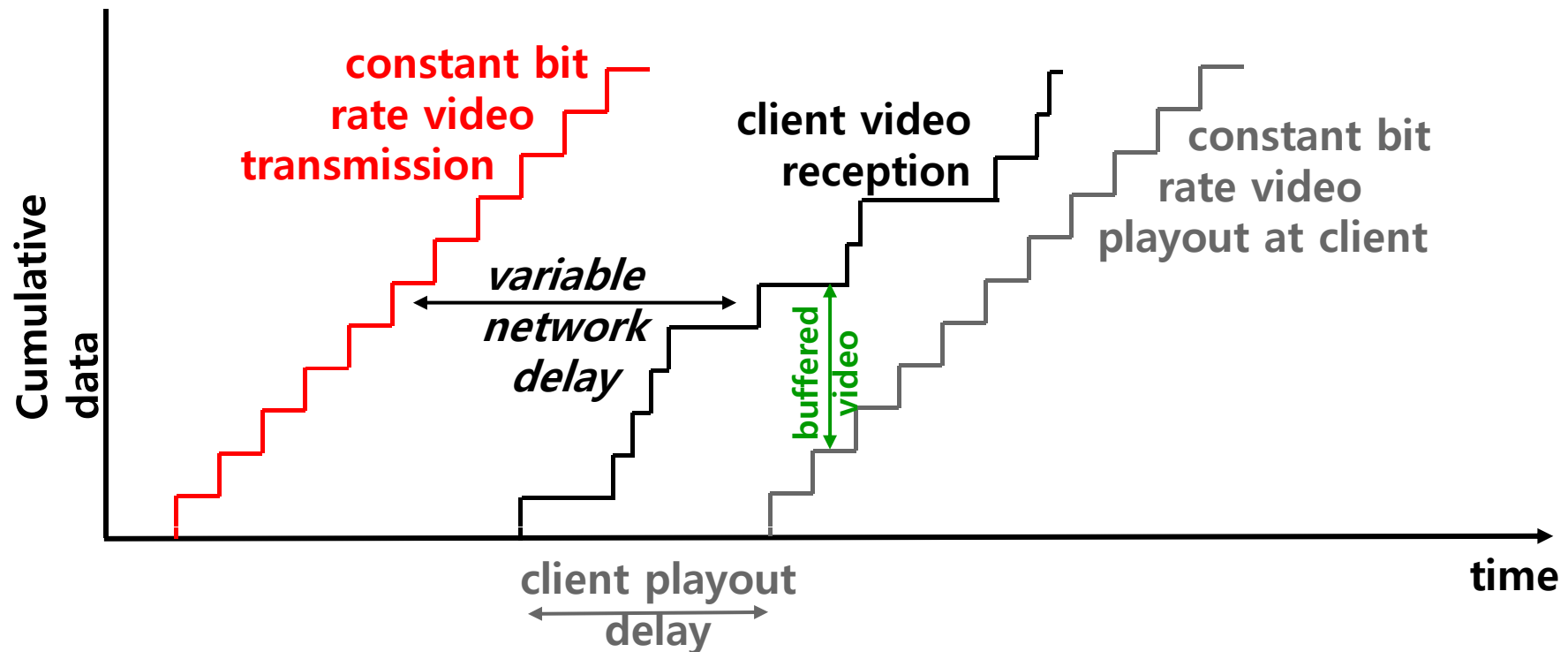
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- Concluding remarks

- Q&A

# Why QoS for multimedia services ? (1)

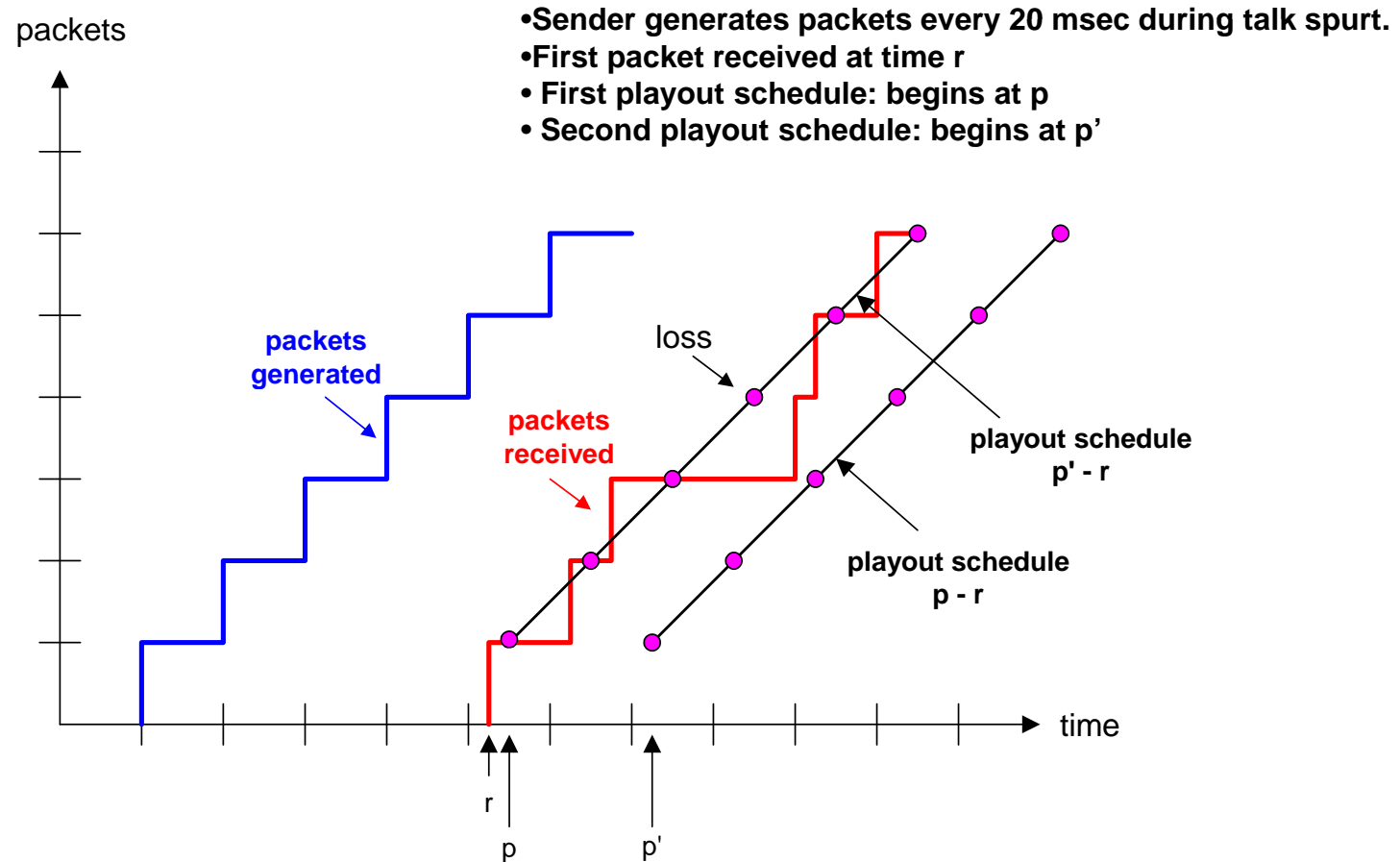


- Playout delay (i.e. Client-side buffering) is required to compensate for network-added delay & delay jitter

Borrowed from Computer Networking, top-down approach by J. Kurose and K. Ross

# Why QoS for multimedia services ? (2)

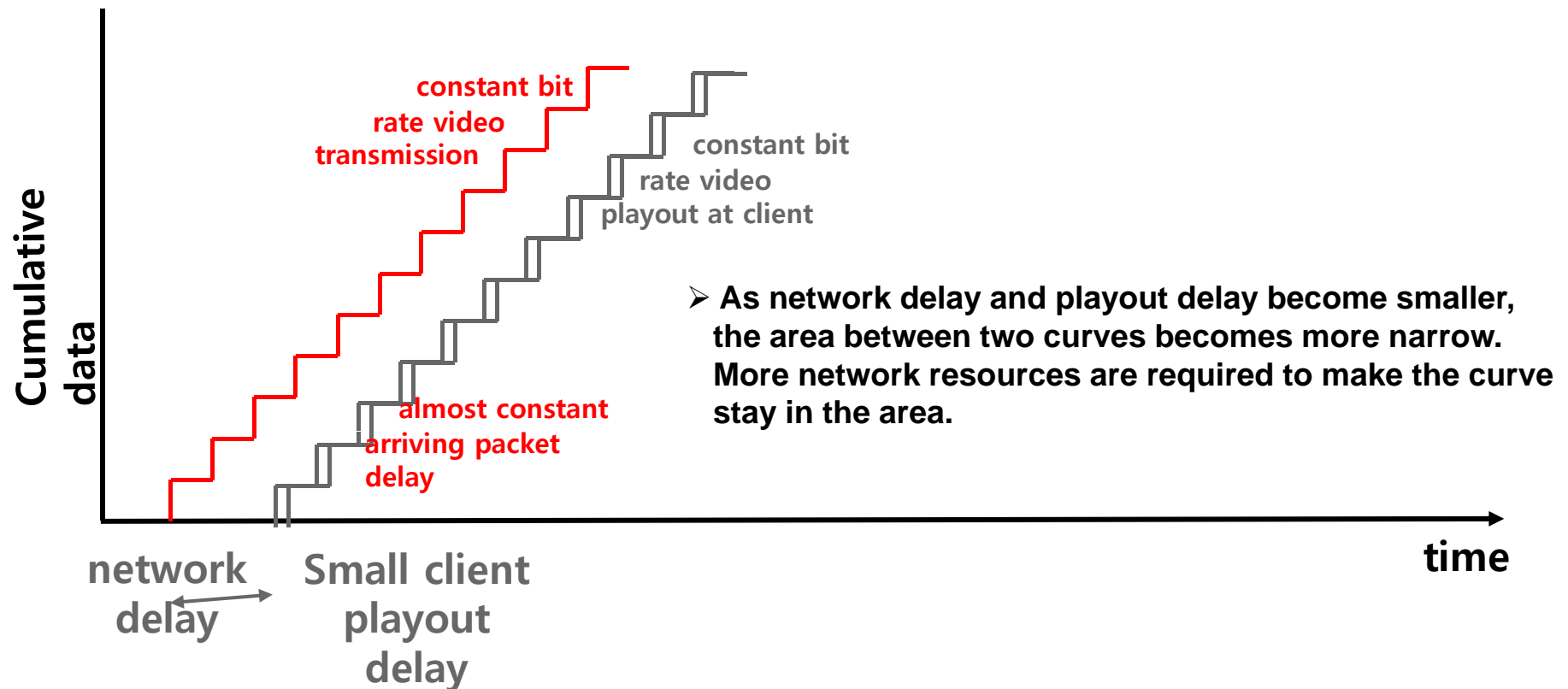
- Over network supporting Best-effort-service



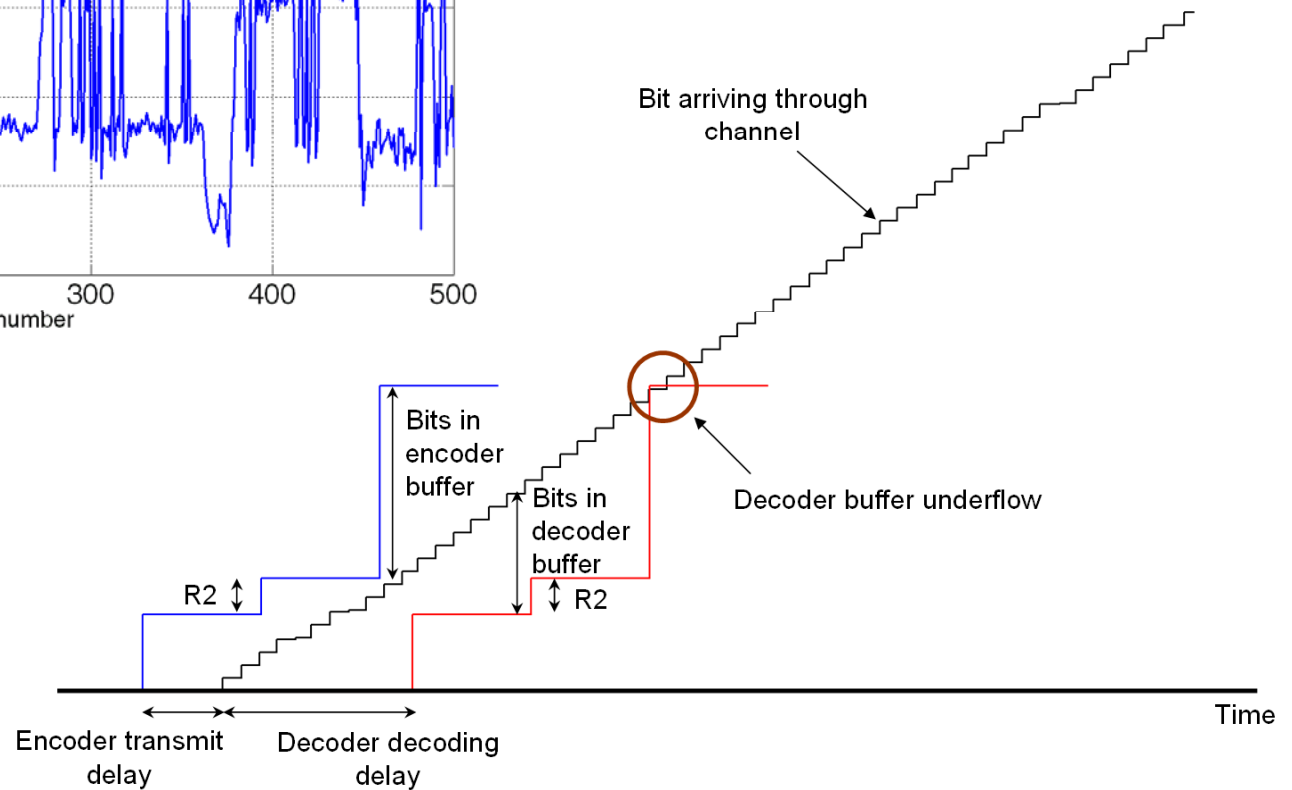
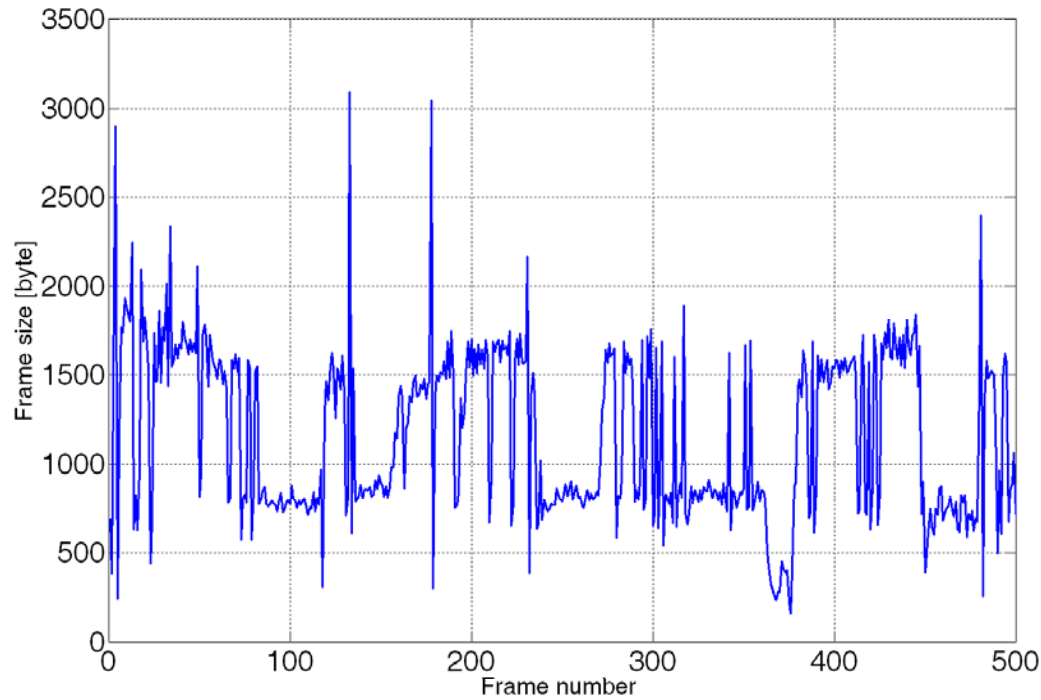
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# Why QoS for multimedia services ? (3)

- over QoS network

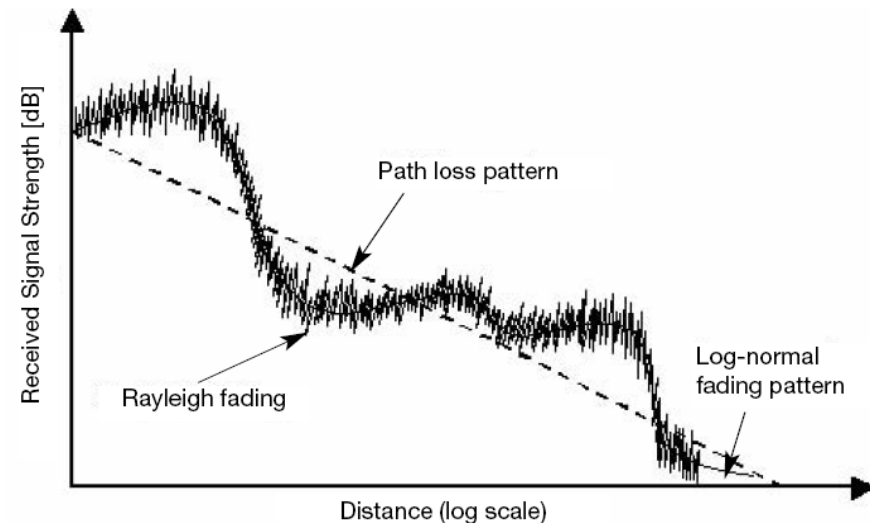


# Burst Characteristics of Multimedia Stream



# Time-varying Wireless Channel

- Dynamically varying Wireless Channel (Network)
  - ◆ Hostile/Time Varying
  - ◆ Bandwidth scarcity/variation
  - ◆ Signal attenuation
  - ◆ (Slow/Fast) Fading
  - ◆ Shadowing
  - ◆ Mobility issue
  - ◆ Collision/Contention, etc



- In summary, it is very difficult to guarantee quality-of-service for multimedia over wireless networks

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# Network Classification

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- In terms of user-centric and media-specific approach
- Can we control network parameters?
  - ◆ Which layers ? & What control variables?
    - Routing, packet scheduling, modulation & code rate, etc. according to the application requirement
  - ◆ Cross-layer approach
- Can we observe (or monitor) network characteristics?
  - ◆ Which layers ? & What network characteristics?
  - ◆ Wide-sense Cross-layer approach
    - Control multimedia data/application-layer parameters based on the observed information

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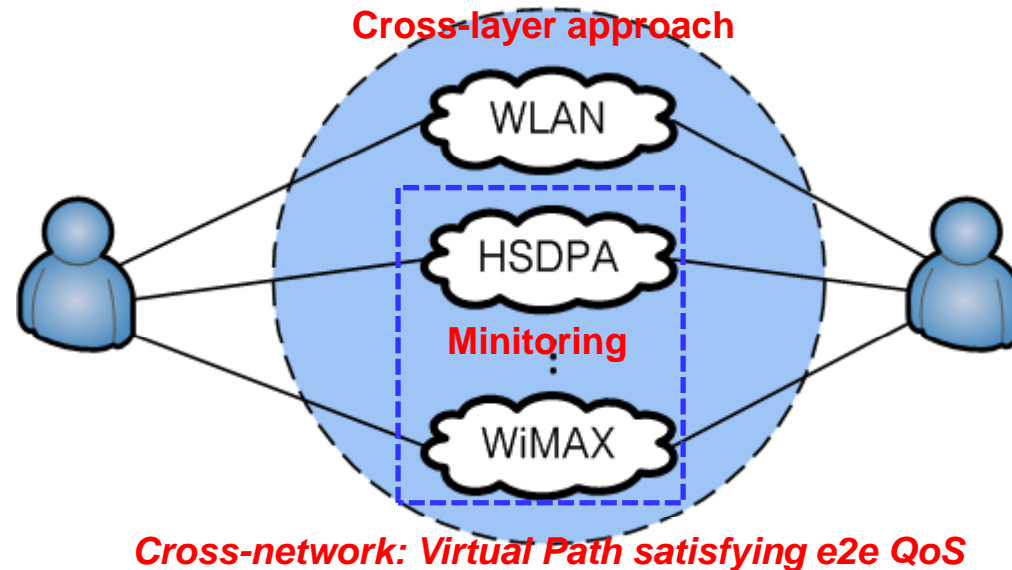
# Current Wireless Network Environment

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- Many wireless networks are already available
  - ◆ Wi-Fi, Bluetooth, Zigbee, IEEE 802.16 (WiMAX/WiBro), etc.
  - ◆ Wireless networks have different characteristics
    - Designed to support their own target applications
  - ◆ Heterogeneous wireless networks co-exist
- It is not expected that a dominant wireless technology can replace all the other wireless technologies soon or later
  - ◆ More wireless networks are expected to emerge for better user experience in the future

# Our Research Goal

- We are trying to find the best combination suitable for multimedia service over network



- We are trying to combine multiple networks to guarantee (or improve) Quality-of-Service for multimedia service
- We are searching for effective & efficient way to integrate multiple networks with heterogeneous characteristics
  - >The cooperation between Telcos and ISPs may be desirable, but do you think it will be realized soon or later?
  - > We don't think so... We are trying to do it at application layer.

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# **Secure End-to-End Path Virtualization for Video Streaming over Multiple Heterogeneous Wireless Networks**

*with Mr. Sangchun Han*

*Partially presented at IEEE CCNC2009*



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# Path Diversity

- Mobile devices with multiple network interfaces are emerging
  - ◆ This kind of devices may become more general in the near future
  - ◆ Successful software defined radio technology will accelerate this trend



Nokia N97



삼성 옴니아 기능 구성



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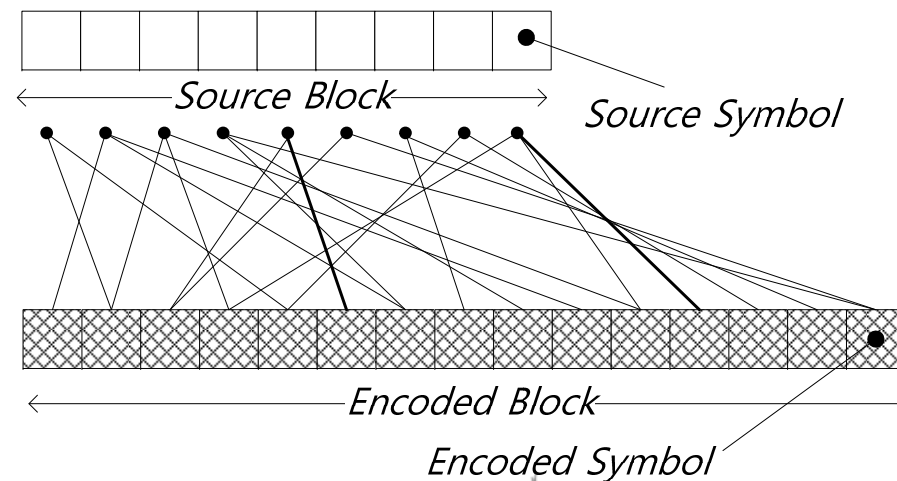
# Advantages of Path Diversity

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- Parallel transmission through multiple paths
  - ◆ Increase total e2e bandwidth
  - ◆ Decrease e2e delay in terms of user
- Paths are independent each other
  - ◆ Compensate burst errors
  - ◆ Increase FEC decoding probability
- Eliminate vertical handoff delay
  - ◆ Without the cooperation/collaboration among the network service providers (e.g. Telcos and ISPs)
- Power consumption may be a little increased to activate multiple network interfaces at the same time

# Fountain Code

- LT code, Raptor code, Online code.
- Rateless code
  - ◆ We can generate Infinite encoded symbols (infinite redundancy)
- Erasure code
  - ◆ It is still decodable although some symbols are lost
- Only very small side information is needed for decoding
  - ◆ By using synchronized pseudo random number generator (e.g. seed number)



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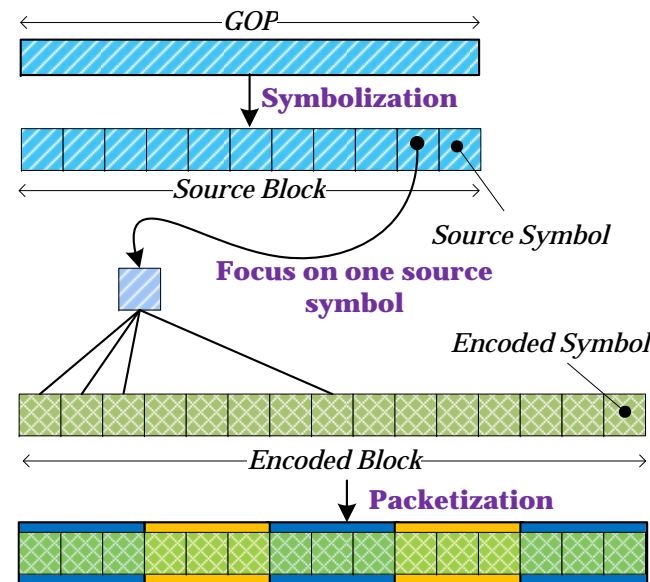
# Advantages of Fountain Code

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- Every available paths (including even unreliable paths) can be used to transmit data
  - ◆ It can eliminate/reduce the packet loss effect by transmitting some of encoded symbols through even unreliable paths
    - We need mechanism to harmonize networks with different characteristics
- Adaptive to wireless channel with time varying characteristics
  - ◆ It can work adaptively to time-varying packet loss rate without additional computational complexity and control overhead
- If successful decoding is guaranteed, then
  - ◆ All packets has the same priority
  - ◆ Simple weighted round-robin scheduling is enough to distribute packets among possible paths

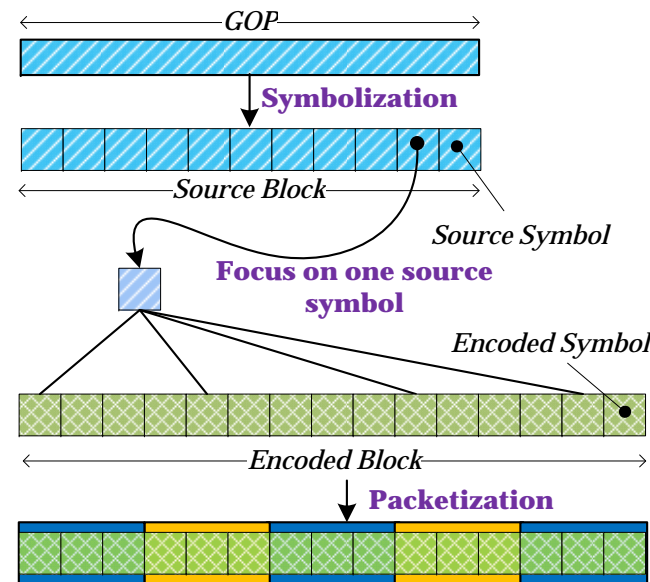
# Packetization-aware Fountain Code (1)

- Video data are delay sensitive
- However, Fountain code requires a huge number of source symbols (more than one thousand symbols) for coding efficiency
  - ◆ Thus, one packet has more than one symbols
  - ◆ When a source symbol has multiple links with a packet, the packet loss may incur the source symbol loss with a high probability over packet switching network.

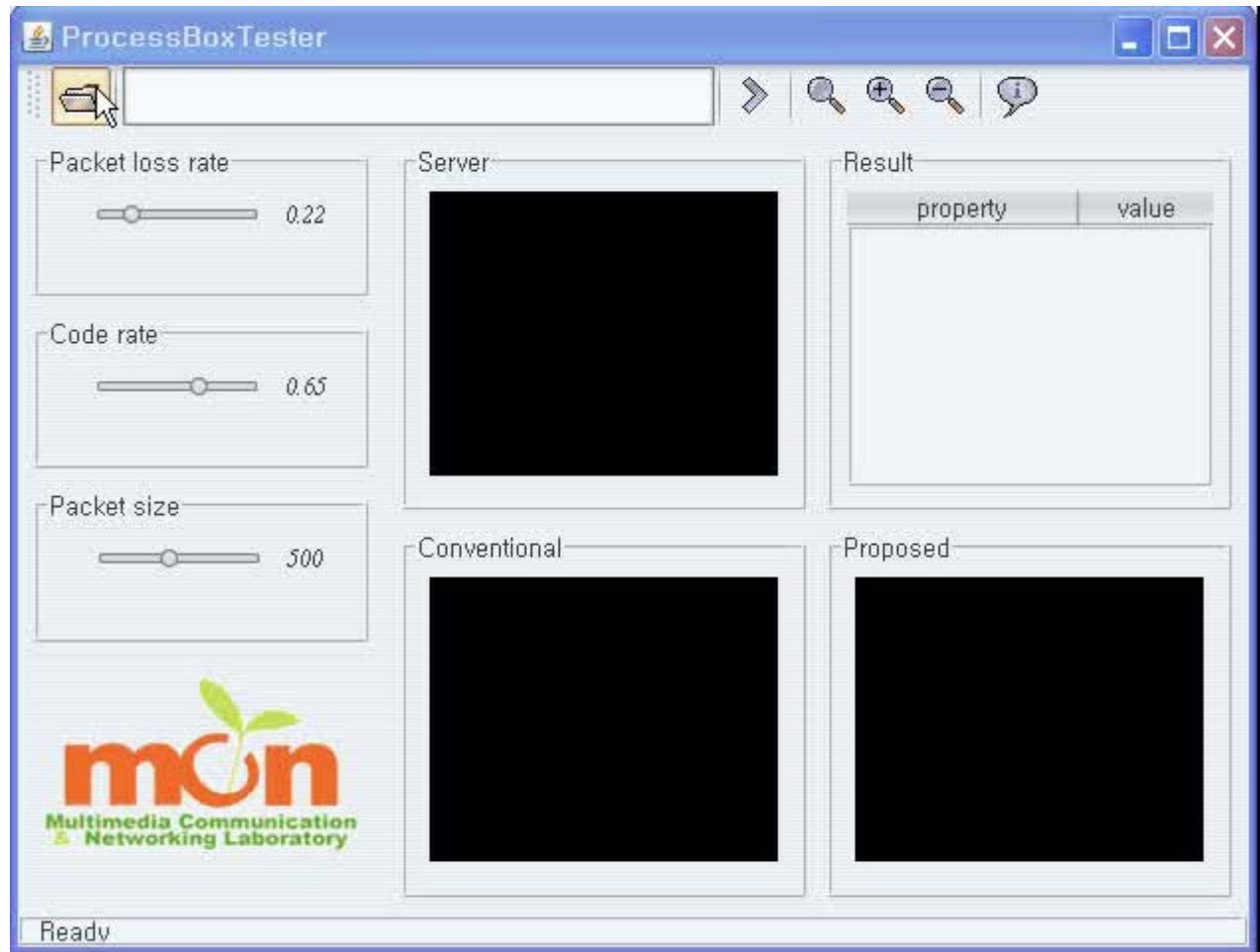


# Packetization-aware Fountain Code (2)

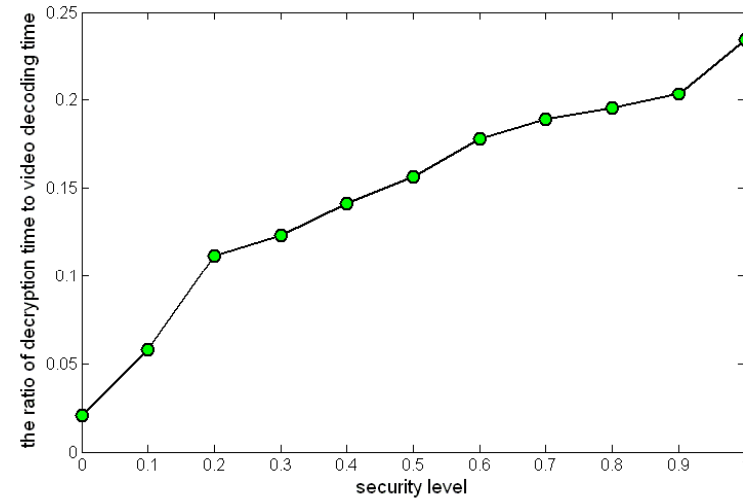
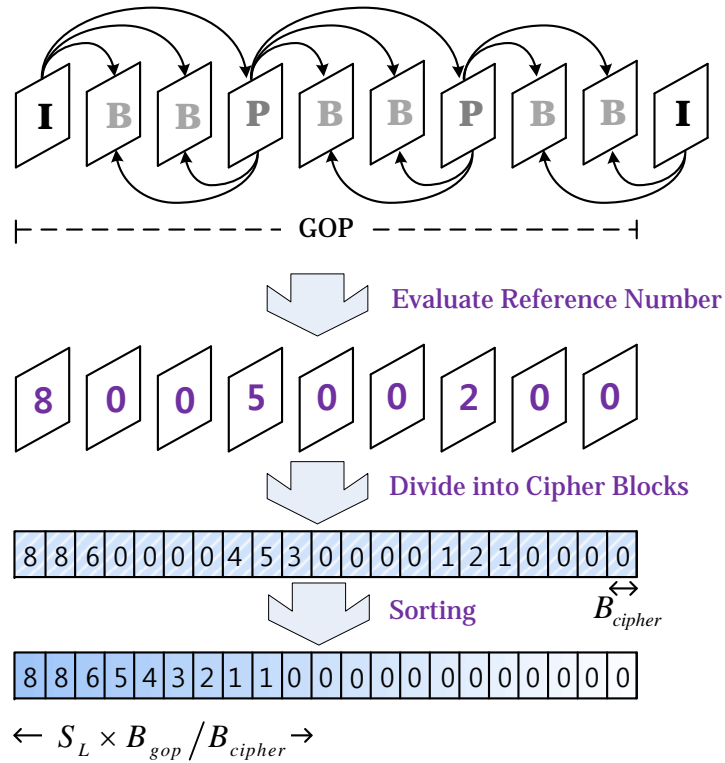
- Packetization-aware Fountain code is required
  - ◆ Need to Control the number of links between source symbols and packets
    - Other encoded symbols in the same packet don't have the additional links to the already selected source symbols
    - The packet loss doesn't severely (dominantly) degrade the decoding performance of any source symbol



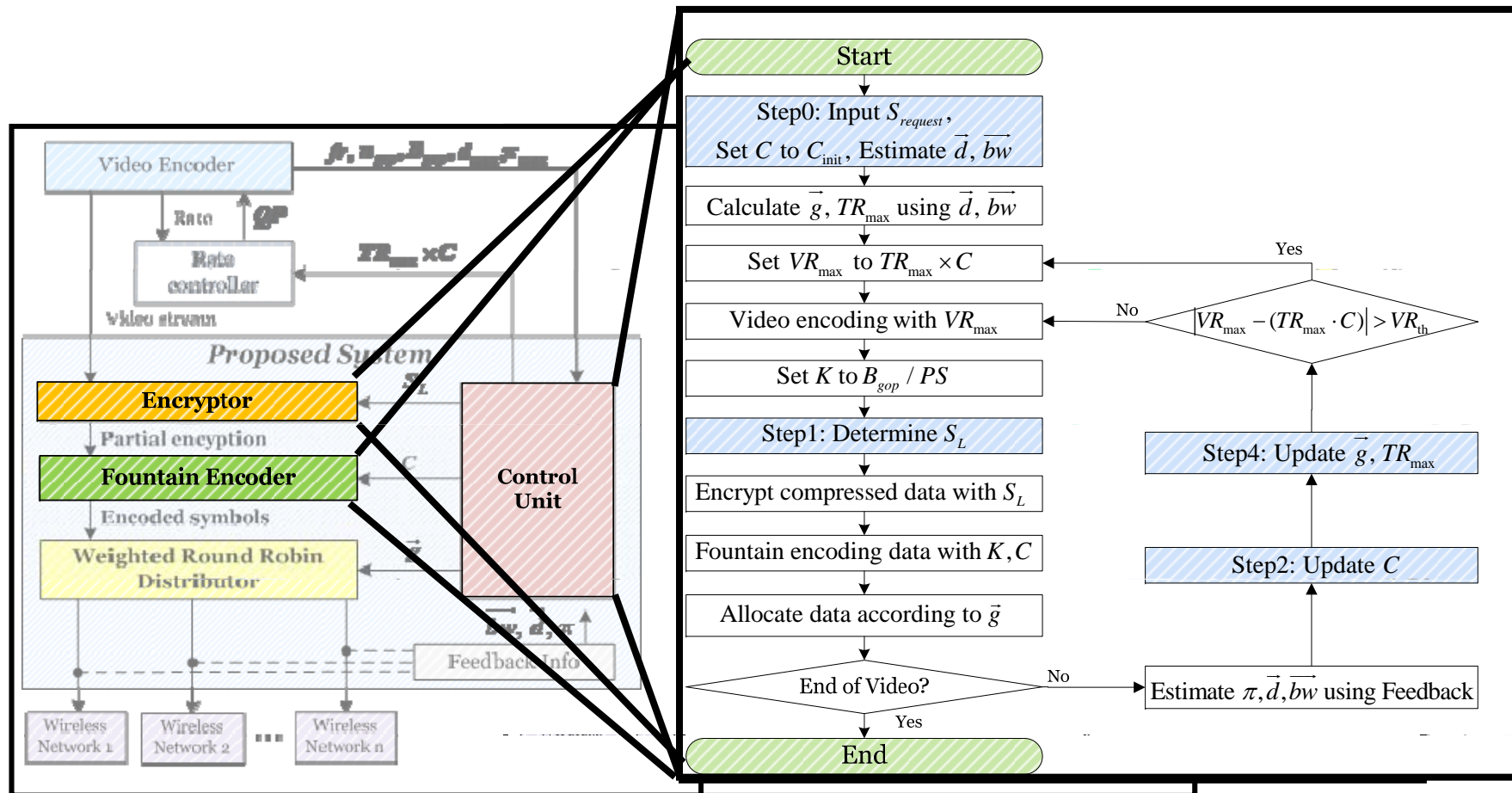
# Simulation of Fountain Code



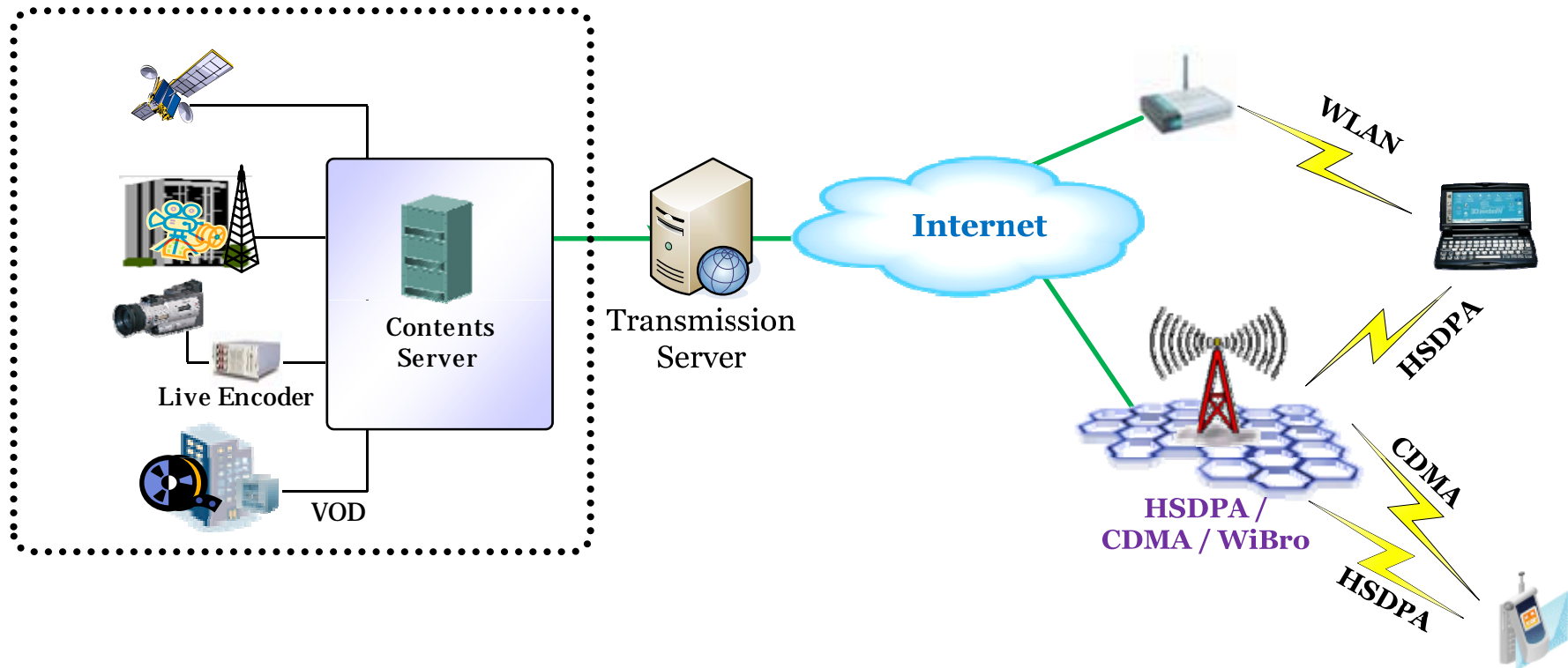
# Partial Encryption of Video



# Overall System

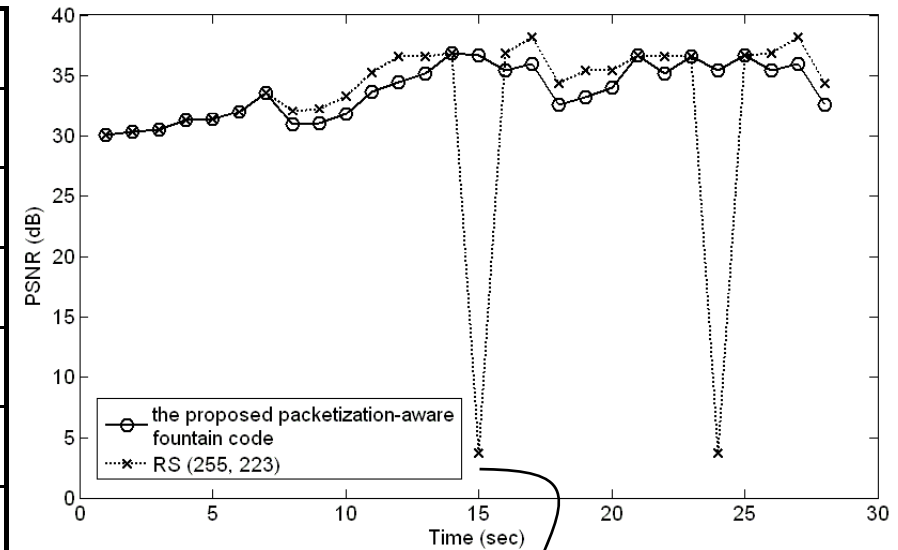


# Demo System



# Experiment Result

Video sequence	Used networks	Avg. PSNR (dB)	Avg. video rate (bps)
Foreman	HSDPA	31.59	126,320
	WLAN	32.57	157,781
	HSDPA and WLAN	34.47	302,245
Harbour	HSDPA	28.16	127,599
	WLAN	29.15	159,828
	HSDPA and WLAN	31.86	311,661
Mobile	HSDPA	24.79	133,178
	WLAN	25.01	168,181
	HSDPA and WLAN	26.78	311,198
Soccer	HSDPA	31.23	119,106
	WLAN	32.13	147,709
	HSDPA and WLAN	34.34	292,783





# Urgency-based Cross-layer Packet Scheduling and Routing Algorithms for Delay-sensitive Media over Mobile Ad Hoc Networks

*With Mr. Ki jin An*

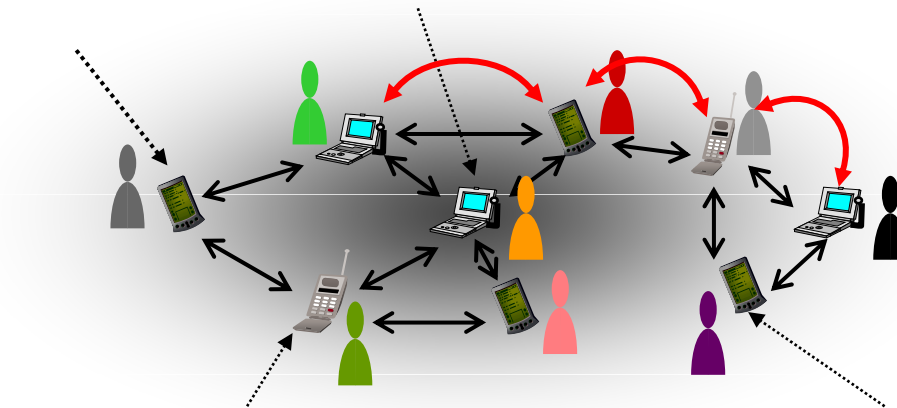
*Partially to be presented at IEEE ICC2009*



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# Mobile Ad Hoc Networks

- maintain the network topology without the help of infrastructure
  - Self-configure among mobile devices
- No wires or cabling



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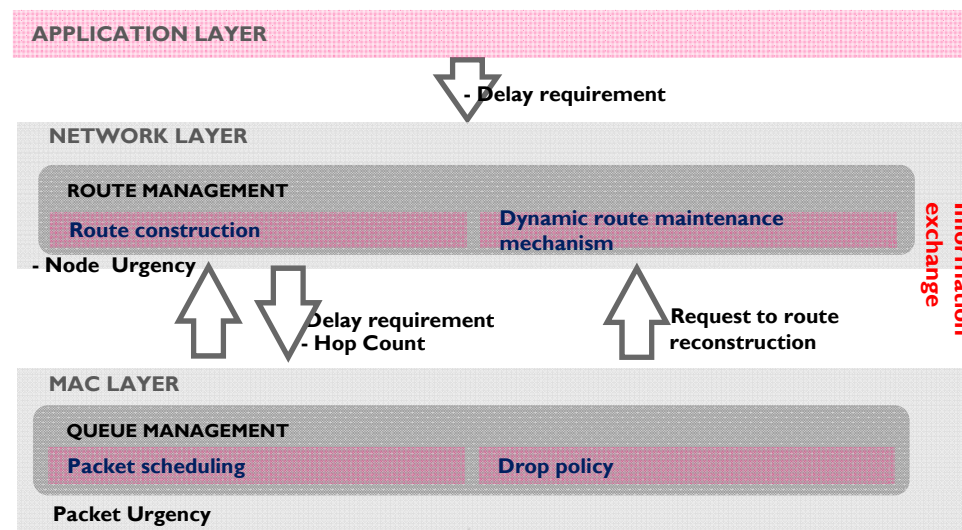
# Challenges in MANET

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- Multi-hop wireless network
  - ◆ Due to the limited transmission power of mobile node
- Cooperation among nodes
  - ◆ Hosts and also serving as Routers
  - ◆ Low capacity per node
  - ◆ In particular, cooperation is required for multimedia transmission since it needs a huge amount of resources compared to traditional services
- Distributed nature of MANET
  - ◆ Channel condition changes continuously
  - ◆ Unpredictable mobility & connectivity
  - ◆ Difficult to acquire the global information
  - ◆ Different demand of host
- We are trying to define a new metric more suitable for multimedia delivery over wireless ad hoc/mesh network

# Motivation

- A Cross-layer algorithm is adopted to efficiently use the limited wireless resources over Mobile Ad Hoc Network
  - ◆ Packet scheduling algorithm and routing algorithm are tightly coupled based on the urgency metrics
    - End-to-end delay requirement and network topology
    - Packet, Node, Route urgency
  - ◆ Suitable for delay-sensitive media delivery over MANET



# Definition of Urgency

- Packet urgency

$$U_{pkt} = D_k^{acc} - D_k^{local}$$

$$\text{where } D_k^{local} = \frac{(k-1) \cdot D_{max}}{N}$$

- Node urgency

$$U_{node} = \sum_{i=1}^{n_k} \max \{ U_{pkt(i)}, 0 \}$$

- Route urgency

$$\sum_{j \in R} U_{node(j)}$$

$D_k^{acc}$

Accumulated delay from sender to the  $k_{th}$  node

$D_{max}$

Required maximum delay

$n_k$

Number of packets staying at queue of a node

# Problem Formulation

- **Problem Formulation:** Determine the packet scheduling & drop policy at each node and all routes to minimize the sum of all route urgency values over the entire network

$$\sum_{m=1}^{n_R} \sum_{j \in R_m} U_{node(j)}$$

- However, it is very complicated to obtain the globally optimal solution
  - Dependency among routes and the interaction between MAC layer and network layer
- Furthermore, it may cause a fairness problem
  - To break other stable existing routes to achieve the global optimal solution while constructing a new route over MANET
- Above problem is divided into two sub-problems to achieve an effective and feasible solution

# Sub-Problem Formulation

- **Sub-Problem Formulation 1 (Packet Scheduling & Drop Policy):** Determine the packet transmission priority and packet drop policy to minimize its node urgency  $U_{node(j)}$  at each node and maximize the number of packets delivered in the tolerable delay bound simultaneously
- **Sub-Problem Formulation 2 (Routing algorithm):** Under the assumption that every node urgency  $U_{node(j)}$  is decided, determine a route ( $R$ ) to minimize the urgency of the route

$$\sum_{j \in R} U_{node(j)}$$

# Additional Header Information

- Successful implementation throughout cross layering and exchanging Packet header information
  - ◆ Route urgency and number of hops is included in route request packet
  - ◆ Additional header information is included in data packet to calculate the packet urgency and node urgency

$\sum_{j \in R_{\text{interim}}} U_{\text{node}(j)}$	$ R_{\text{interim}} $
Accumulated route urgency	The number of hops over a route

## Additional header information in RREQ packet

$D_{\text{max}}$	$ R $	$P_i^{k-1}$	$D_k^{\text{acc}}$	$ts^{\text{prev}}$	$hcnt^k$
Delay requirement	Number of hops over the route	Data packet priority at the previous hop	Accumulated delay	Timestamp at the previous hop	Current hop count

## Additional header information in data packet

# Proposed Packet Scheduling

- Packet transmission priority is designed to minimize the node urgency
- **Rule 1: Data packet priority at initial hop:**

$$p_i^1 = \frac{1}{|R|} D_{\max}$$

- **Rule 2: Data packet priority at intermediate hops:**
  - ◆ Less urgent packet decreases its priority for more urgency transmission
  - ◆ More urgent packet increases its priority for satisfying the delay requirement
  - ◆ Progressive priority change
    - Abrupt packet priority change is sometimes a big burden to the next node

$$p_i^k = p_i^{k-1} - \alpha \cdot U_{pkt} = p_i^{k-1} - \alpha \cdot \left( D_k^{acc} - \frac{k-1}{|R|} D_{\max} \right), \quad \text{for } k > 1$$

- **Rule 3: Control packet priority:**
  - Highest transmission priority to the above routing packets

# Proposed Packet Drop Policy

- Proposed packet drop policy determines which packets must be dropped by investigating the packet head information
- **Case 1 : Delay-constrained packets**
  - ◆ Accumulated delay is larger than the specified  $D_{\max}$
  - ◆ Packets with smaller  $D_{\max}$  are dropped with higher probability when network traffic is heavy
- **Case 2 : Queue is overflowed by the newly arriving packets**
  - ◆ Performance is degraded if the relayed packets that are very close to the destination in the case of the multi-hop transmission
  - ◆ Node drops the packet with the maximum possibility not to arrive at its destination. The possibility is defined by

$$\frac{|R_{pkt(i)}| - hcnt_{pkt(i)}}{|R_{pkt(i)}|} U_{pkt(i)} - \frac{1}{|R_{pkt(i)}|} D_{pkt(i)}^{\max}$$

# Proposed Routing algorithm

- The proposed routing algorithm selects a route with the minimum route urgency instead of the shortest route

$$\min_R \sum_{j \in R} U_{node(j)}$$

- **Rule 1: Route construction mechanism:**
  - ◆ Each node updates its node urgency  $U_{node(j)}$  during the sorting of the queue every time a new packets arrives
  - ◆ RREQ packet is updated and re-broadcasted to the neighbors
  - ◆ Destination selects the route with minimum route urgency
  - ◆ Other nodes participating in the route construction procedure maintain or update their link information
- **Rule 2: Dynamic route maintenance mechanism:**
  - ◆ Packet urgency level is too high to meet the end-to-end delay requirement at a node over the current route
  - ◆ Node issues RERR and a new route is established by **Rule1** even though the current path is still stable

# Dynamic route maintenance mechanism

**Algorithm** *issueNewRoute( period )*:

```
f ← maxCountFlow(drop _ packets)
IF f.count < threshold THEN
    period' ← increase(period)
    IF period' ≥ MAX _ RERR THEN
        period' ← MAX _ RERR
    END IF
    issueNewRoute(period')
ELSE
    requestNewRoute(f)
    period' ← decrease(period)
    IF period' ≤ MIN _ RERR THEN
        period' ← MIN _ RERR
    END IF
    issueNewRoute(period')
END IF
```

- Nodes record the number of dropped packets and its corresponding flow ID
- Nodes select the flow whose packets are dropped with the most frequency within the period of time
- The packet drop counting interval is adjusted to avoid unnecessary route reconstructions

*drop \_ packets* : numbers of the dropped packets in the flows during the period

*maxCountFlow*(*drop \_ packets*) : function to find the flow with the largest number among *drop \_ packets*

*f.count* : number of the dropped packet in the flow *f*

*period* : time interval to call the *issueNewRoute*

*increase*(*period*), *decrease*(*period*) : functions to adjust the *period*

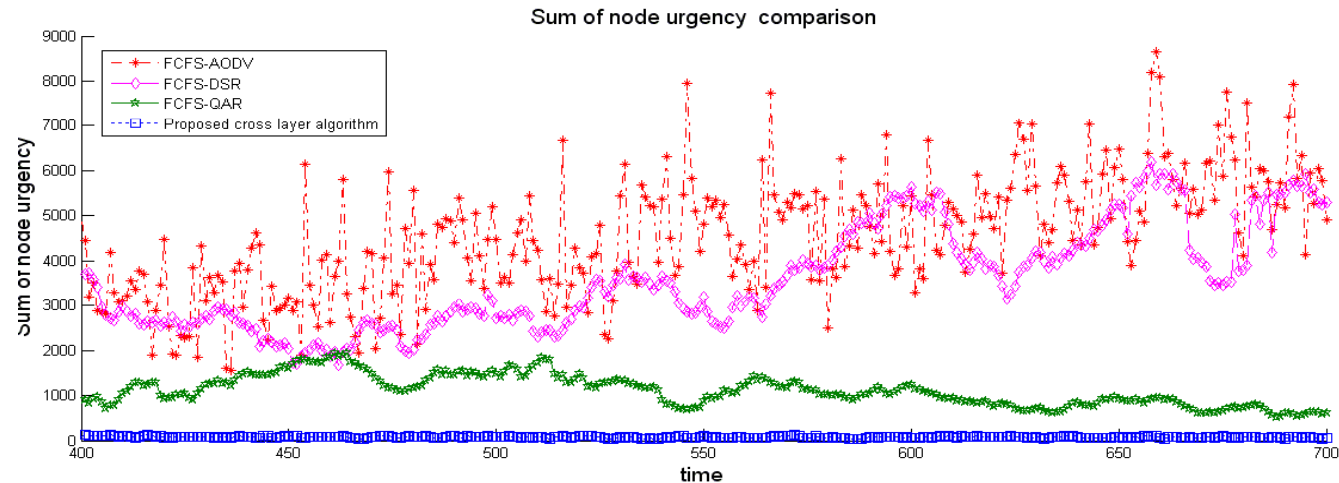
*MIN \_ RERR* / *MAX \_ RERR* : minimum/maximum value of *period*

*requestNewRoute*(*f*) : function to make the source node of the flow *f* build a new route

# Simulation Setup

- ns-2 simulator
- 50 mobile nodes at 500 x 500m
- Random waypoint model (speed : 0~5m/s, pause time : 100~300sec)
- Connections {5, 10, 15, 20, 25, and 30} , arbitrarily selected pairs of sender and receiver
- $D_{\max}$  is set to 1.0sec or 3.0sec arbitrarily for each flow
- All senders generate an average of 20 packets/sec whose size is 512-kbytes with exponential inter arrival time
- Maximum queue size : 50 packets
- IEEE 802.11 MAC
- Dropped packet counting interval period 1.5~ 5sec(with step size 0.5sec)
- Smoothing factor  $\alpha = 1$
- The resulting numbers of the experiment : average values obtained from several repeated random scenarios(Simulation time: 1000s)
  
- Performance Comparison
  - FCFS-AODV, FCFS-DSR, FCFS-QAR, Proposed algorithm
  - Urgency Metrics
  - End-to-End QoS Metrics

# Experimental Result(1)

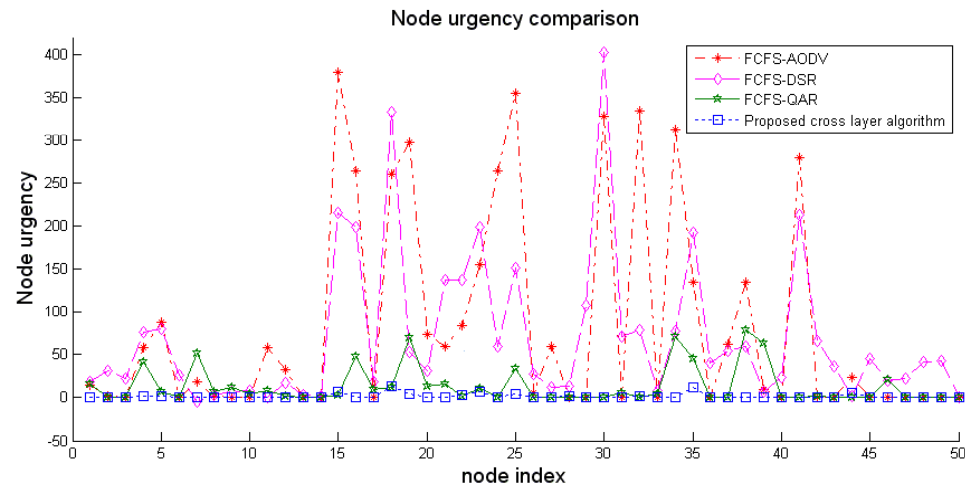


	AVG of urgency over the entire network	MAX of urgency over the entire network	STD of urgency over the entire network
FCFS-AODV	$4.16 \times 10^3$	$1.77 \times 10^4$	$3.00 \times 10^3$
FCFS-DSR	$3.50 \times 10^3$	$6.90 \times 10^3$	$1.68 \times 10^3$
FCFS-QAR	662.61	$1.99 \times 10^3$	496.89
Proposed cross layer	68.03	146.27	32.86

Sum of node urgency over the entire network and its statics

The urgency metric is closely related to traffic load. *FCFS-AODV* shows a very high total urgency value whose curve suddenly increases when traffic is concentrated to some nodes and/or network congestion occurs

# Experimental Result(2)



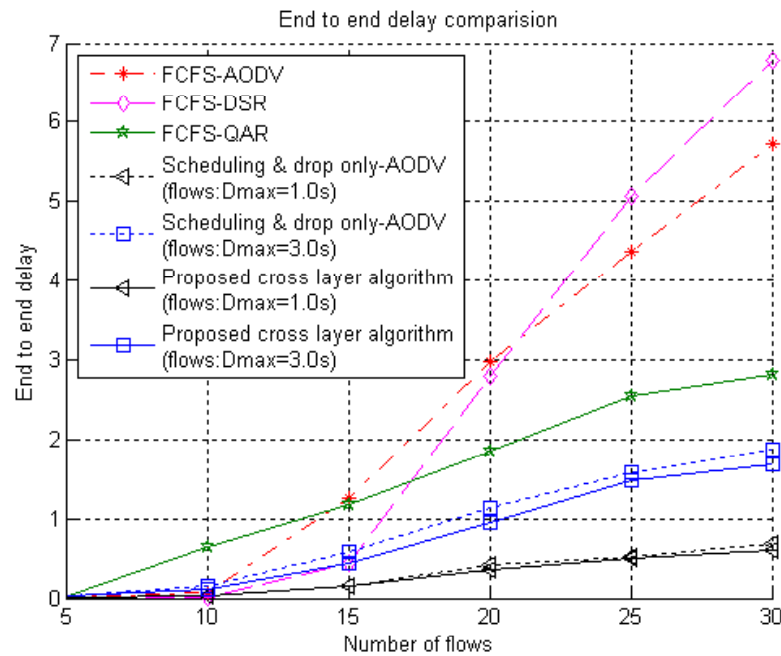
	AVG of node urgency values	MAX of node urgency values	STD of node urgency values
FCFS-AODV	$4.16 \times 10^3$	$1.77 \times 10^4$	$3.00 \times 10^3$
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FCFS-QAR	662.61	1985	496.89
Proposed cross layer	68.03	146.27	32.86

Node urgency comparison at each node and active nodes' statics

Urgency is obviously concentrated to some active nodes in the case of *FCFS-AODV* and *FCFS-DSR*.

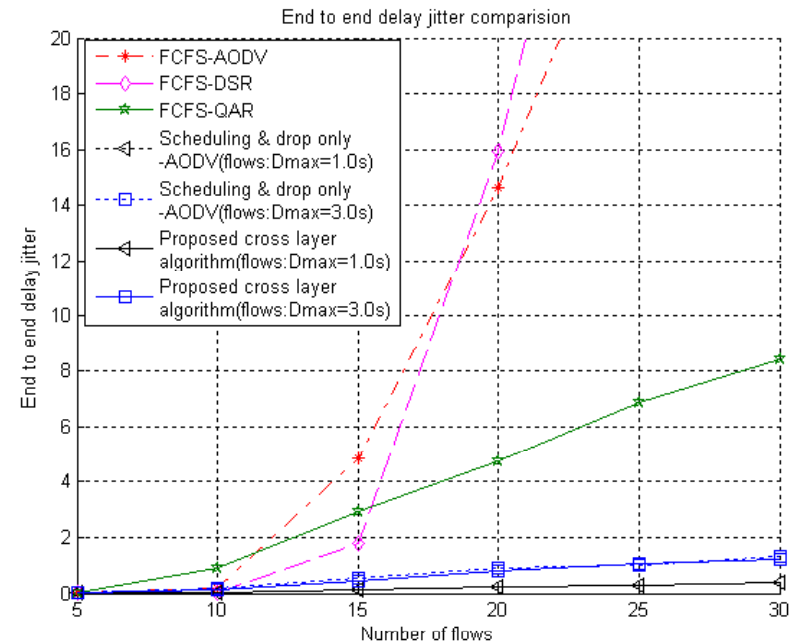
*The proposed algorithm* can almost equally distribute the urgency to active nodes participating in data forwarding

# Experimental Result(3)



End-to-end delay comparison

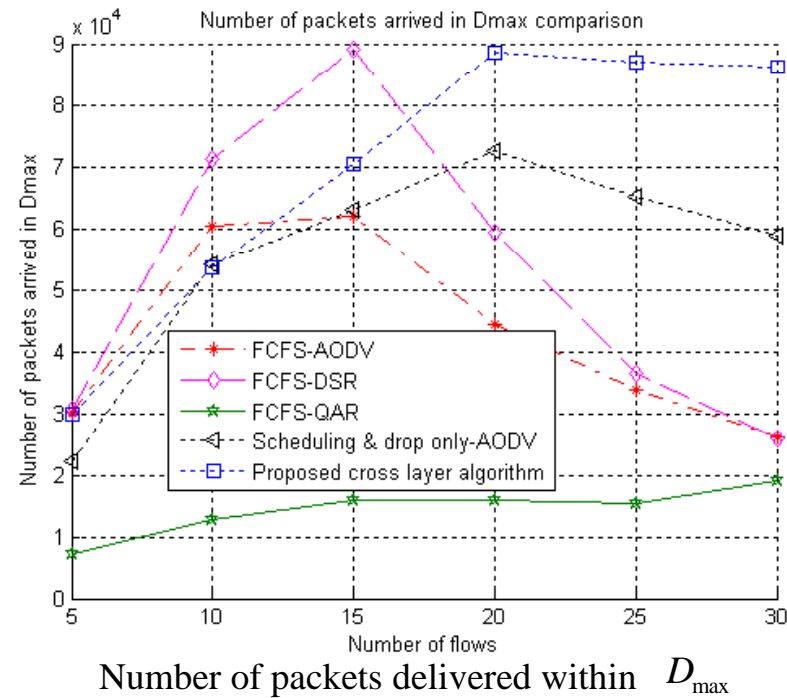
*Proposed algorithm* satisfies the end-to-end delay constraint until the number of flows reaches 30.



End-to-end delay jitter comparison

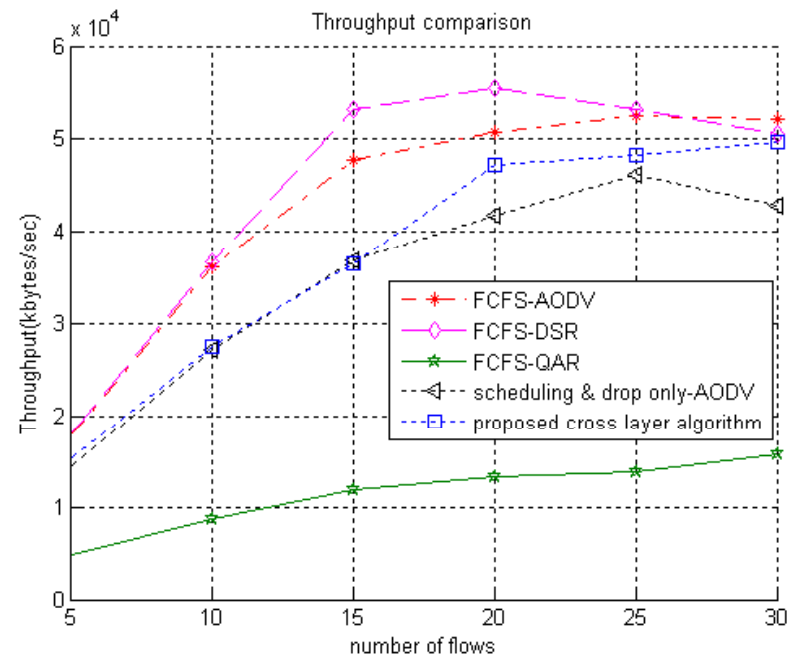
Jitter is defined as the variance of packet arriving delay. The jitter curve of *the proposed algorithm* still remains in the very small range.

# Experimental Result(4)



*Proposed cross layer algorithm* performs better than any other algorithm when the number of flows is larger than 17. Because it distributes the traffic load to the entire network and properly controls the packet transmission priority.

# Experimental Result(5)

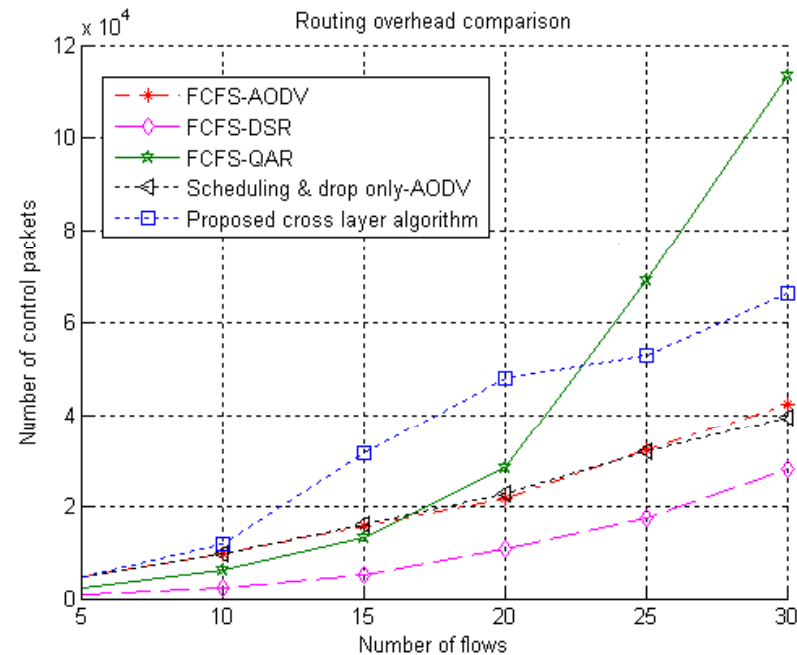


Throughput comparison

*QAR* supports the lowest throughput because only admitted flows can be transmitted.

Performance of *the scheduling & drop only Scheme*'s degraded due to frequent packet drops when the network is congested.

# Experimental Result(7)

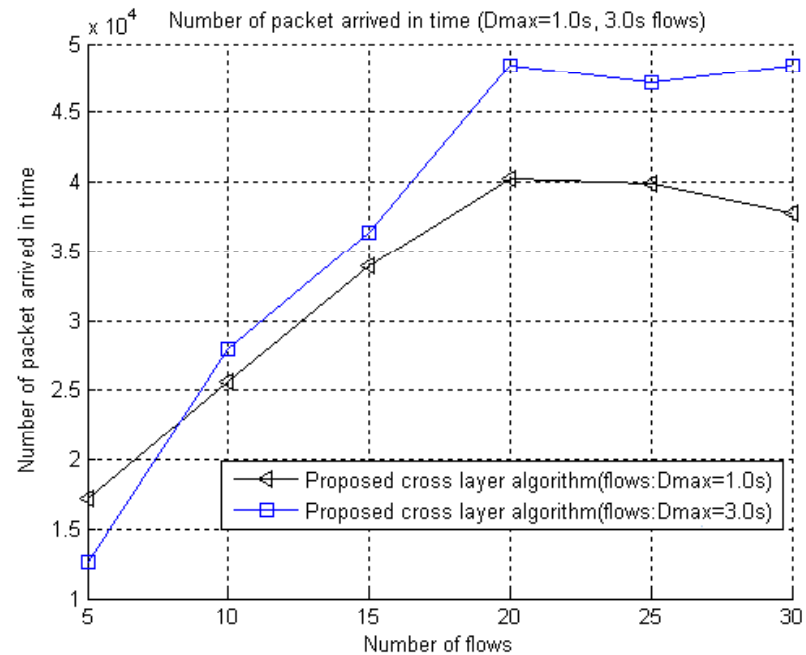


Routing overhead comparison

*The proposed cross layer algorithm* also requires some routing control packets for the dynamic route maintenance.

*QAR* requires the routing overhead to estimate the available channel resource.

# Experimental Result(8)



Number of packet arrived in time

Greedy senders receive better service when the traffic load is very light over the entire network. However, as the traffic load becomes heavy, more packets arrive in the tolerable delay bound when  $D_{\max}$  becomes larger, and vice versa.

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# Concluding Remarks

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- ❑ Cross-layer approach
  - Which layers & parameters are controllable/observable?
  - We are trying to find the best combination suitable for multimedia service over network
  
- ❑ Cross-network approach
  - We are trying to combine multiple networks to guarantee (or improve) Quality-of-Service for multimedia service
  - We are searching for effective & efficient way to integrate multiple networks with heterogeneous characteristics
  
- ❑ We are pursuing globally optimal solution w.r.t. user (or content) by combining Cross-layer & Cross-network approaches

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Thank you for your attention

Q/A

Send inquiry to [hwangjun@postech.ac.kr](mailto:hwangjun@postech.ac.kr)  
<http://mcnl.postech.ac.kr>