A High Rate Wireless Packet Data System with Versatile QoS Support

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QoS Provision in a Wireless Packet System

- **Inter-user and intra-user quality of service (QoS)**
  - Differentiate data packets with various levels of QoS
  - Treat data flows differently based on their QoS requirements
  - Support multiple QoS flows per user
- **Reverse link (RL) QoS support**
  - RL physical layer hybrid ARQ
  - Multi-flow fluid media access control (MAC)
- **Forward link (FL) QoS support**
  - Existing scheme: Provide QoS support with a QoS-sensitive scheduler
  - Additional FL QoS Support:
    - Small packets and multi-user packets for delay-sensitive applications (gaming, etc.)

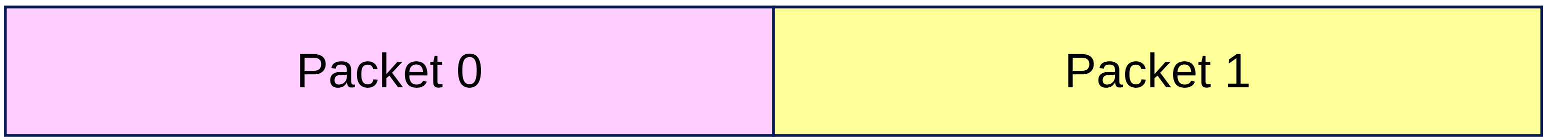
RL Physical Layer Hybrid ARQ

- **Flexible packet length with incremental transmission**
  - **Each physical layer packet is transmitted for up to four 4-slot subpackets**
    - **Each slot is 1.67 ms long**
  - **8-slot interval between successive transmissions of the same packet**
  - **Three 4-slot HARQ interlaces**
- **Physical layer hybrid ARQ**
  - **ACK/NAK sent on forward link for every subpacket**
  - **Subpackets of a packet are soft-combined ––– incremental redundancy**
  - **Early termination improves throughput as well as delay performance**

RL Hybrid ARQ Operation

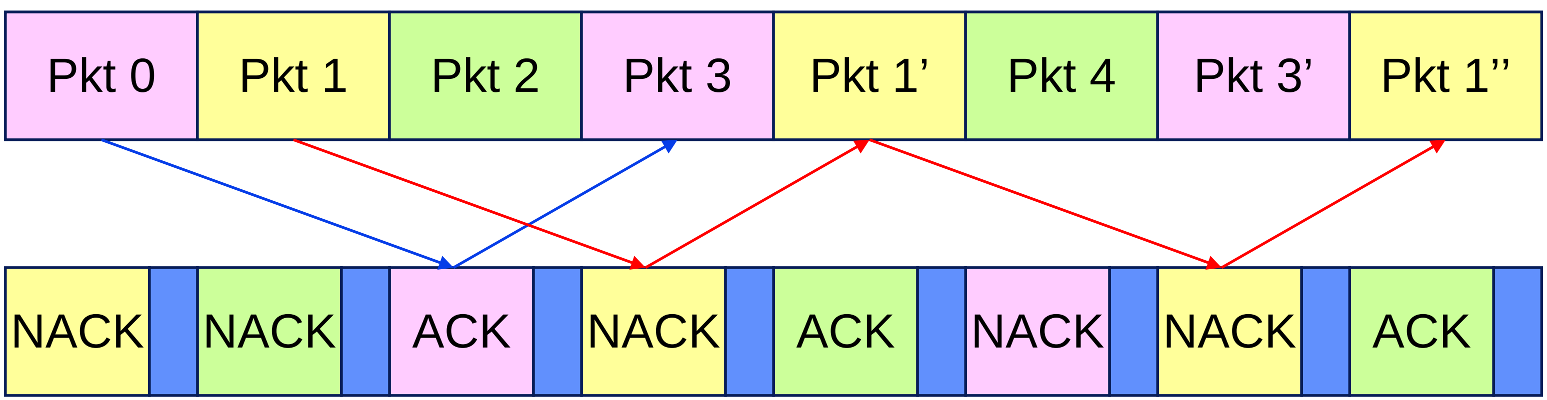
1 RL Packet = 16 slots = 26.67 ms

Current Reverse Link



1 RL subpacket = 4 slots = 6.67 ms, three interlaces, 12 slots between subpackets of a packet

New Reverse Link



(FL ARQ Channel)

Enhanced RL Packet Structures (1)

Payload Size (bits)	Modu-lation	Effective Data Rate (kbps)				Code Rate [Repetitions]			
		After 4 Slots	After 8 Slots	After 12 Slots	After 16 Slots	After 4 Slots	After 8 Slots	After 12 Slots	After 16 Slots
[1] 128	BPSK	19.2	9.6	6.4	4.8	1/5 [3.2]	1/5 [6.4]	1/5 [9.6]	1/5 [12.8]
[2] 256	BPSK	38.4	19.2	12.8	9.6	1/5 [1.6]	1/5 [3.2]	1/5 [4.8]	1/5 [6.4]
[3] 512	BPSK	76.8	38.4	25.6	19.2	1/4 [1]	1/5 [1.6]	1/5 [2.4]	1/5 [3.2]
[4] 768	BPSK	115.2	57.6	38.4	28.8	3/8 [1]	1/5 [1.07]	1/5 [1.6]	1/5 [2.13]
[5] 1024	BPSK	153.6	76.8	51.2	38.4	1/2 [1]	1/4 [1]	1/5 [1.2]	1/5 [1.6]

Note: Current (payload, data rate) configurations are highlighted in blue

Enhanced RL Packet Structures (2)

Payload Size (bits)	Modu-lation	Effective Data Rate (kbps)				Code Rate [Repetitions]			
		After 4 Slots	After 8 Slots	After 12 Slots	After 16 Slots	After 4 Slots	After 8 Slots	After 12 Slots	After 16 Slots
[6] 1536	QPSK W4	230.4	115.2	76.8	57.6	3/8 [1]	1/5 [1.07]	1/5 [1.6]	1/5 [2.13]
[7] 2048	QPSK W4	307.2	153.6	102.4	76.8	1/2 [1]	1/4 [1]	1/5 [1.2]	1/5 [1.6]
[8] 3072	QPSK W2	460.8	230.4	153.6	115.2	3/8 [1]	1/5 [1.07]	1/5 [1.6]	1/5 [2.13]
[9] 4096	QPSK W2	614.4	307.2	204.8	153.6	1/2 [1]	1/4 [1]	1/5 [1.2]	1/5 [1.6]
[10]6144	QPSK W4 & W2	921.6	460.4	307.2	230.4	1/2 [1]	1/4 [1]	1/5 [1.2]	1/5 [1.6]
[11]8192	QPSK W4 & W2	1228.8	614.4	409.6	307.2	2/3 [1]	1/3 [1]	2/9 [1]	1/5 [1.2]
[12]12288	8-PSK W4 & W2	1843.2	921.6	614.4	460.8	2/3 [1]	1/3 [1]	1/3 [1.5]	1/3 [2]

QoS Support at RL Physical Layer (1)

- **Latency improvement**
  - Terminals have the ability to boost transmit power to force packet termination after the first, second or third subpacket transmission
    - The power boost procedure is regulated by RL MAC algorithm to meet latency requirement of delay-sensitive applications (e.g., gaming)
  - Ability to start a new packet at any 4-slot boundary
    - Mean queuing delay is reduced to two slots (compared to eight slots before)
- **Flexible tradeoff between capacity and latency**
  - Use longer packets to achieve better coding gain and time diversity $\Rightarrow$ higher capacity
  - Use shorter packets (with power boosting) to reduce transmission time $\Rightarrow$ shorter delay

QoS Support at RL Physical Layer (2)

- **MAC layer ARQ**
  - **Enhanced reliability of the last ARQ message for a packet**
  - **Detect erased physical layer packet and provide retransmission directly at the MAC layer**
  - **Result in fewer RLP layer retransmissions**
  - **Improvement in throughput and delay**

RL Sector Throughput Comparison
(57-Sector Embedded Simulation)

DO Rev. 0, No ARQ, 600 Hz PC					
Chan. Model	Num AT	Sect Cap kbps	AvgROT dB	Delay ms	
A	10	367	5.1	40.0	*3 km/h*
B	10	275	5.4	40.0	*10 km.h*
C	10	283	5.3	40.0	*30 km/h*
D	10	355	5.1	40.0	*120 km/h*
E	10	472	5.1	40.0	*Rician*
A	4	287	3.5	40.0	*3 km/h*
B	4	240	4.1	40.0	*10 km.h*
C	4	243	4.1	40.0	*30 km/h*
D	4	285	3.6	40.0	*120 km/h*
E	4	357	3.5	40.0	*Rician*

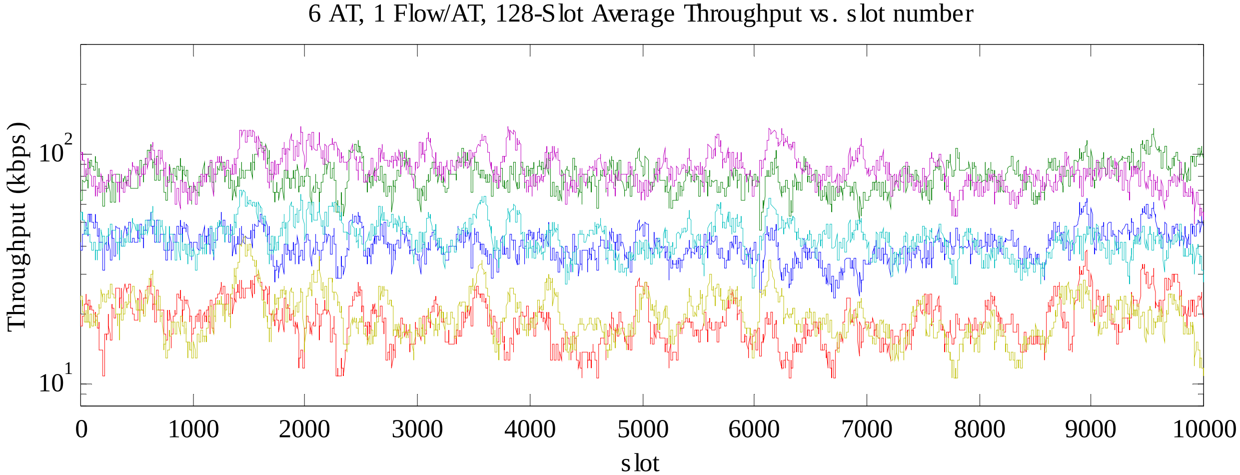
DO Rev. A, 8-slot termination, 150 Hz PC					
Chan. Model	Num AT	Sect Cap kbps	AvgROT dB	4-sl ET %	Delay ms
A	10	304	5.2	83.9	13.2
B	10	245	5.3	71.2	15.8
C	10	257	5.2	74.9	15.0
D	10	404	5.1	70.1	16.0
E	10	600	5.2	51.3	19.7
A	4	408	4.5	83.2	13.4
B	4	310	4.8	68.0	16.4
C	4	331	4.7	71.3	15.7
D	4	462	4.6	60.0	18.0
E	4	773	4.8	31.4	23.7

	DO Rev. A, 16-slot Termination, 150 Hz PC							
	Chan. Model	Num AT	Sect Cap kbps	AvgROT dB	4-sl ET %	8-sl ET %	12-sl ET %	Delay ms
3 km/h	A	10	667	5.2	15.0	62.8	88.9	36.7
10 km.h	B	10	521	5.3	9.6	50.4	87.7	40.5
30 km/h	C	10	543	5.2	13.6	60.0	90.5	37.2
120 km/h	D	10	691	5.1	4.0	46.2	88.6	42.2
Rician	E	10	912	5.3	0.9	18.7	78.5	50.4
3 km/h	A	4	776	4.6	10.2	57.56	87.66	38.9
10 km.h	B	4	661	4.8	5.79	44.07	85.87	42.9
30 km/h	C	4	687	4.7	8.44	54.66	89.26	39.5
120 km/h	D	4	816	4.6	1.41	36.91	85.81	45.2
Rician	E	4	1001	4.9	0.11	12.07	75.07	52.6

RL MAC Enhancement

- Ease of design for QoS
  - Rapid control of relative throughput and delay among application flows
  - Unified approach to inter-user and intra-user QoS
  - Differentiation of flows within an access terminal (AT) is treated in the same way as flows from different ATs
- Improved performance for bursty and fixed-rate sources
  - Reduced delay and delay variance
  - Rapid and efficient resource usage
- Improved closed-loop control of system loading
  - More predictable ROT dynamics
- Enhanced access channel reduces call setup time
  - Shorter and more flexible preamble length
  - Allow access channel data rates up to 38.4 kbps
- Flexible rate allocation at each AT via autonomous as well as scheduled mode
- Compatible with existing physical layer

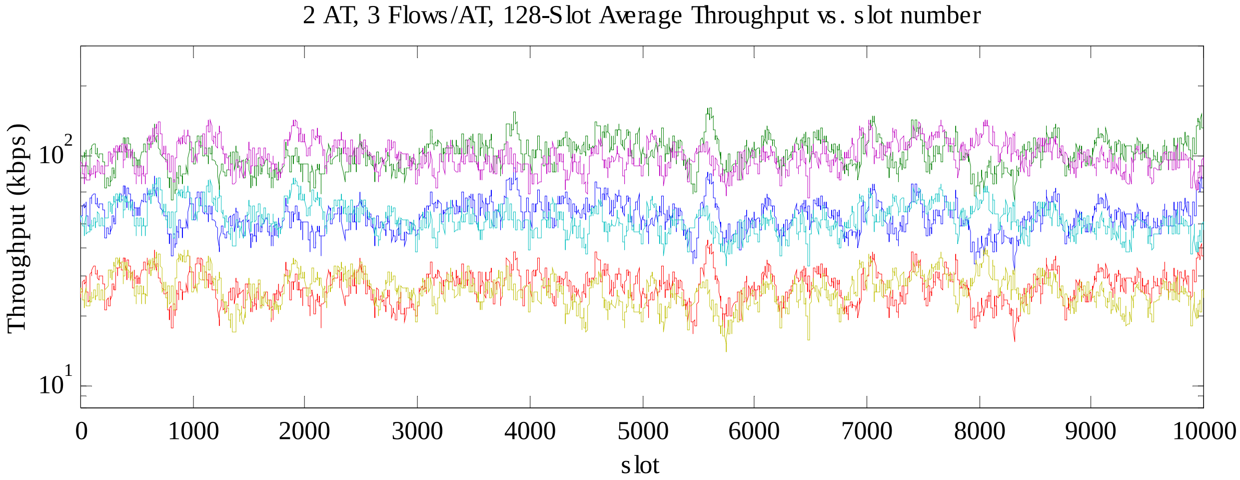
Example of Unified Approach to Inter-user and Intra-user QoS



Inter-user QoS

6 AT's: 1 Flow/AT

Flow Priority = {4,4,2,2,1,1}



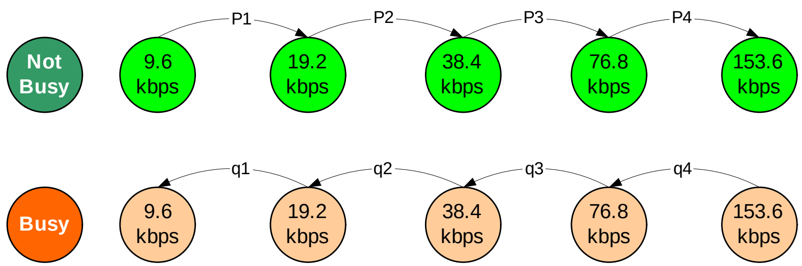
Intra-user QoS:

2 AT's: 3 Flows/AT

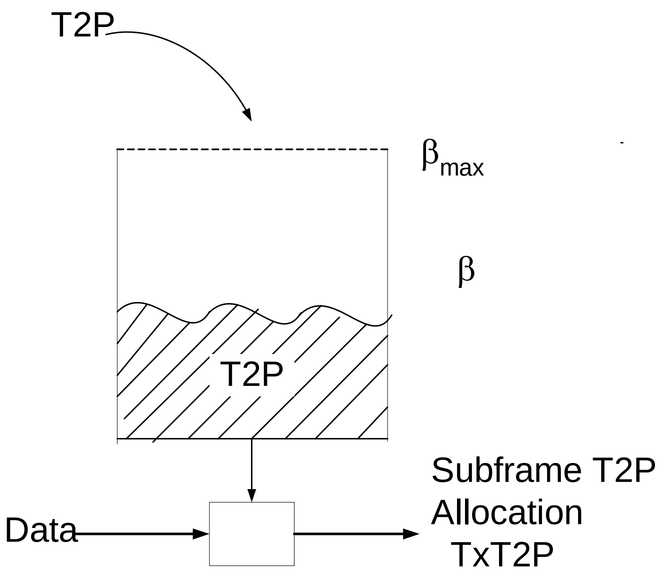
Flow Priority = {4,2,1} {4,2,1}

RLMAC Operation

- **Current RL Mac**
  - Probabilistic rate determination at the AT based on Reverse Activity Bit (RAB)



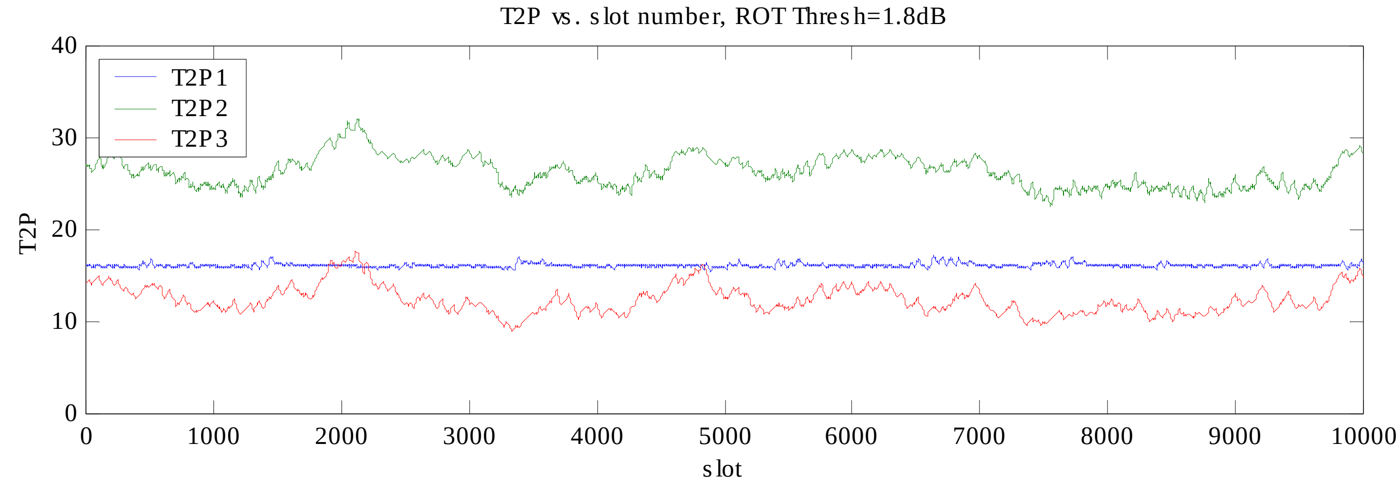
- **Enhanced RL MAC**
  - If QRAB = 1 (busy), reduce AT's continuous state variable T2P by gd(.)
  - If QRAB = 0 (not busy), increase T2P by gu(.)
  - The actual transmit rate is chosen for each packet such that the average matches the state variable T2P

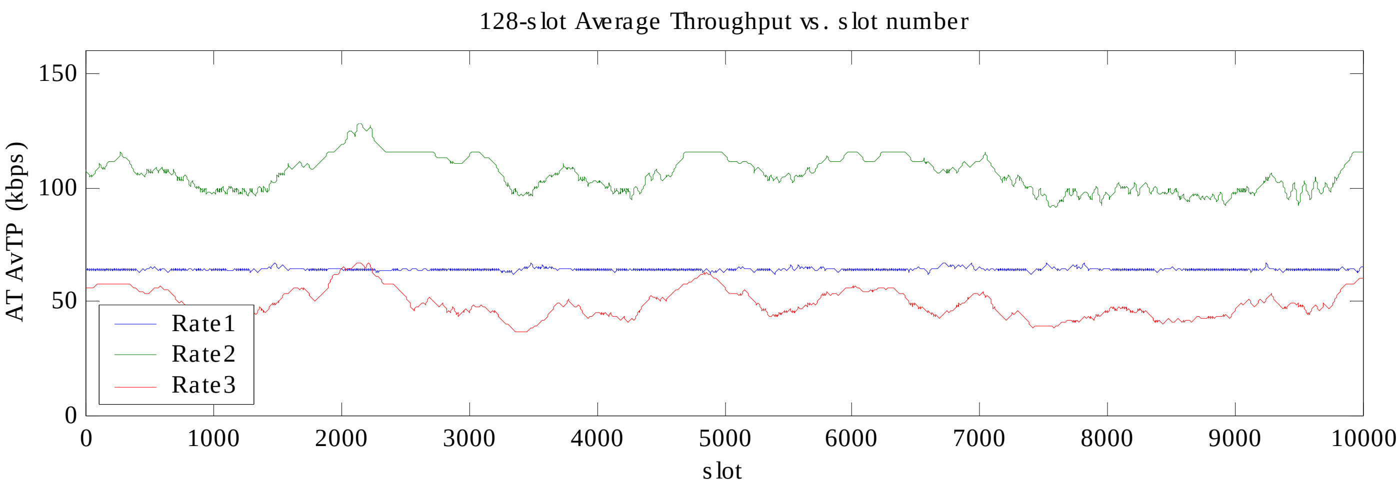


QoS Design in RL MAC

- T2P relative priority
  - Flows can be allocated relative priority, specified by the relative priority weighting C_i
    - C_i indicates the flow's relative sector resource usage, in relation to other relative priority flows
    - $C_i = 2C_j$ implies that flow i should get twice the throughput of flow j when they have the same active set
    - Ramp functions gu(.) and gd(.) for flow i are determined based on C_i
- T2P fixed allocation
  - Flows can be allocated a fixed T2P, specified as $T2P_{fix}$
  - The flow very quickly achieves a $T2P_{fix}$ allocation, but may be restricted from going beyond it
- Source burstiness design
  - Flows with bursty sources may transmit a high-rate burst after being idle for sometime
  - Flows are designed with a burstiness constraint, specified as $\beta_{fact}(T2P)$
  - $\beta_{fact}(T2P)$ indicates the max factor above the current T2P allocation which can ever be used in one allocation
  - Allows efficient handling of bursty sources while under average T2P allocation

T2P Allocation Example:
One Flow at Fixed T2P = 16
Two at Relative Priority C = 0.5, 1.0

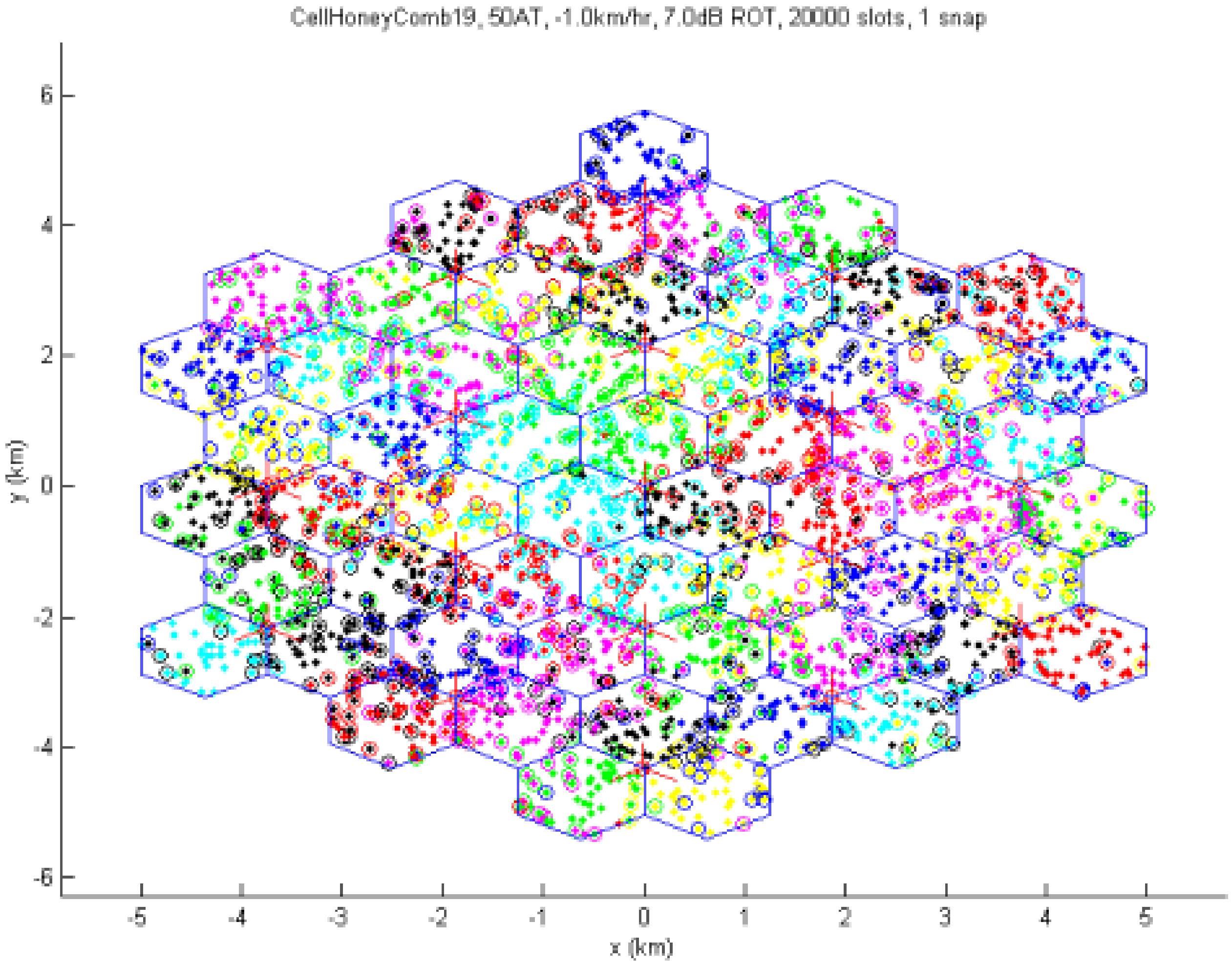




Reverse Link Application Performance Evaluation

- Simulations run under 3GPP2 Evaluation Methodology
  - 19-cell, 57-sector layout with wraparound
  - Mix of 5 channel models with various fading velocities and multipath
  - Link budget scaled to cdma2000© overlay for application simulation
- Data source models
  - VoIP
    - TIA/EIA IS-871 Markov Service Option (MSO) for cdma2000 Spread Spectrum Systems model used for voice
      - Average rate 3.2 kbps
      - Multiplex Option 0x01 used (8kbps), no blanking, minimum rate of 1/8
    - 4-frame bundling (80 msec)
      - Design for max delay 160 msec (80 msec bundling + 80 msec transmission)
      - 16-slot termination goal
  - Gaming
    - 9.6 kbps fixed rate
      - Fixed packet size arriving every 40 msec
  - Video
    - Simple video source which models 10 fps QCIF video source
      - 43 kbps of video, fixed packet size arriving every 100 msec
      - Same audio as in VoIP case, IS-871 MSO

Performance Evaluation
57-Sector Layout

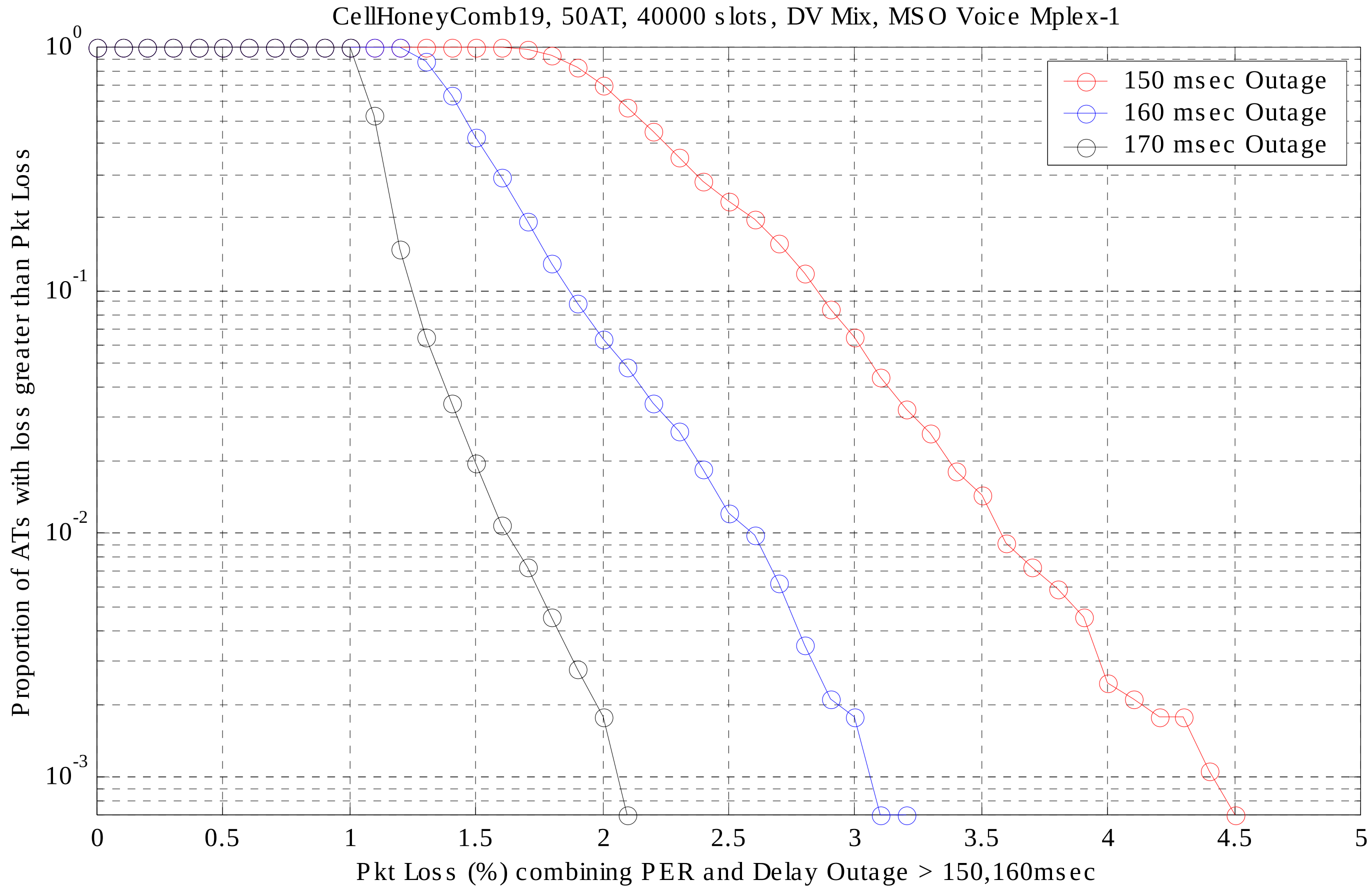


RL Applications Performance

Criteria		1xEV-DO Rev 0	1xEV-DO Rev A
VoIP Capacity	# Users/Sector	34	50
	Packet Loss < x % with Delay Outage > y ms	(2%, 170 ms)	(2%, 160 ms)
Gaming Capacity	# Users/Sector	25	30
	Mean Packet Delay	40 ms	17 ms
Video Telephony Capacity	# Users/Sector	6	10
	Packet Loss < x % with Delay Outage > y ms	(10%, 200 ms)	(2%, 200 ms)

RL VoIP Capacity, AT Packet Loss Statistic

57-Sector, 50 AT/Sector, Rev. A, DO Link Budget



Forward Link QoS Enhancements

- Enhanced QoS support via small packets
  - Addition of new small payload sizes: 128 bits, 256 bits, 512 bits
  - Enables FL scheduler to better serve delay-sensitive data to users in adverse channel conditions
  - Small packets for control channel improves paging performance
- Packet division multiplexing
  - Multiplexing small upper-layer packets from one or more users into a single physical-layer packet
  - Enables FL scheduler to serve data from different QoS flows to one or more users simultaneously
  - Improved link utilization while serving delay sensitive applications
- Data Source Control (DSC) Channel introduced (on RL) to indicate the desired forward-link serving cell
  - Minimize service interruption due to server switching on FL
  - Improved user experience for applications such as wireless gaming and video telephony

Concluding Remarks

- An wireless packet data system providing advanced QoS support is described
- Commercial systems are being built based on this design
- cdma2000 1xEV-DO (1x Evolution – Data Optimized) = TIA-856 standard
  - Revision A contains all the enhancements described herein