Interference-Aware Radio Resource Management Framework for the 3GPP LTE Uplink with QoS Constraints

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Agenda

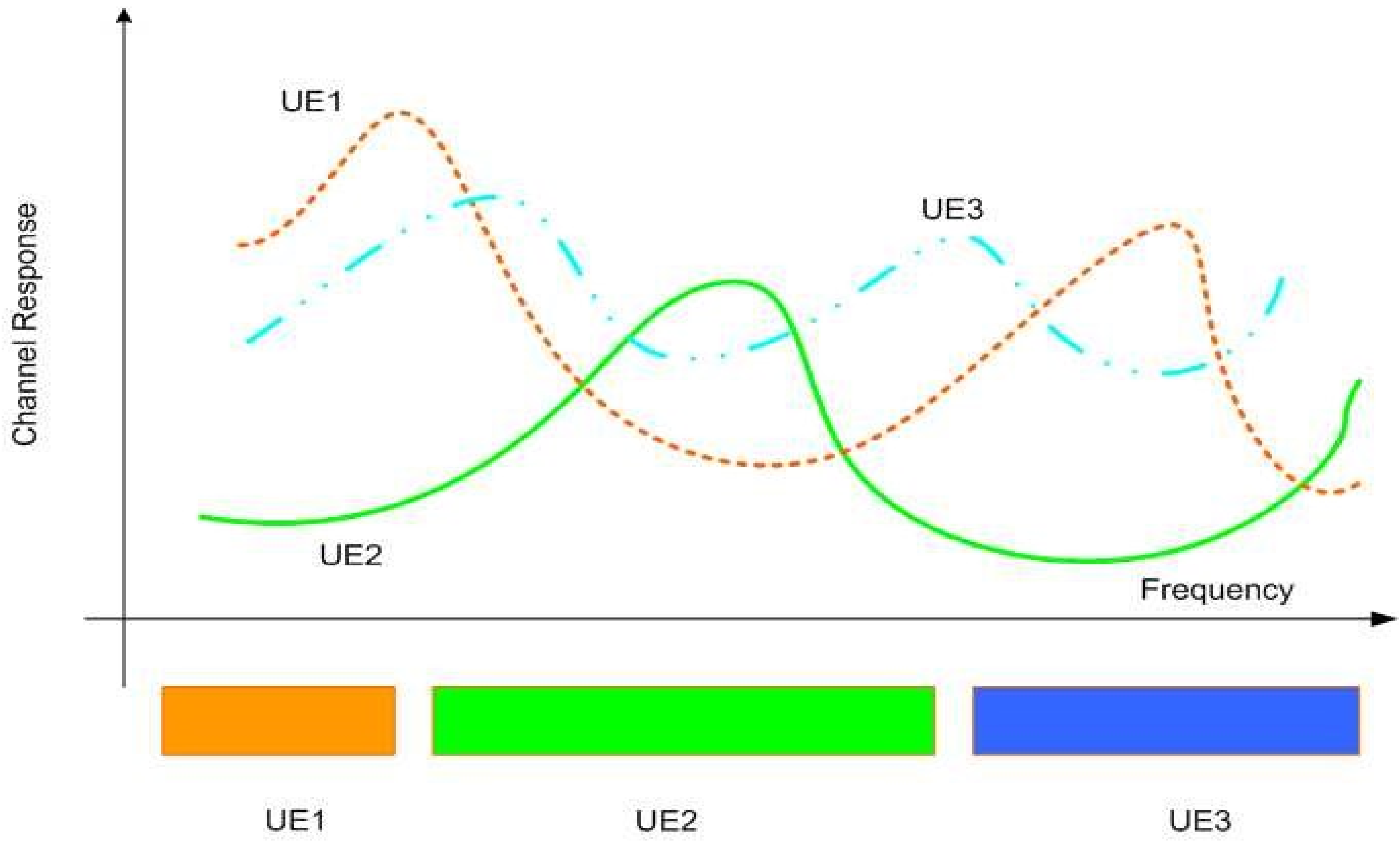
- Introduction
- Uplink Scheduling Design Problem and Constraints
- System Model
- Proposed Framework
- Performance Evaluation
- Conclusions

Introduction

- To offer high data rates LTE exploits OFDM technology in the downlink and SC-FDMA in the uplink
- SC-FDMA is a Discrete Fourier Transform (DFT)-spread version of OFDM
  - Low peak to average power ratio (PAPR) saves the constrained power for the User Equipment (UE)
  - Retains the multipath fading resistance of OFDM and the flexibility in sub-carrier allocation
- LTE uses adaptive coding and modulation and power control to enhance uplink performance
- Uplink scheduling is not comprehensively studied due to complexity arising from the many constraints
- Tradeoff exists between PRB allocation and power allocation

Uplink Scheduling Design Problem and Constraints

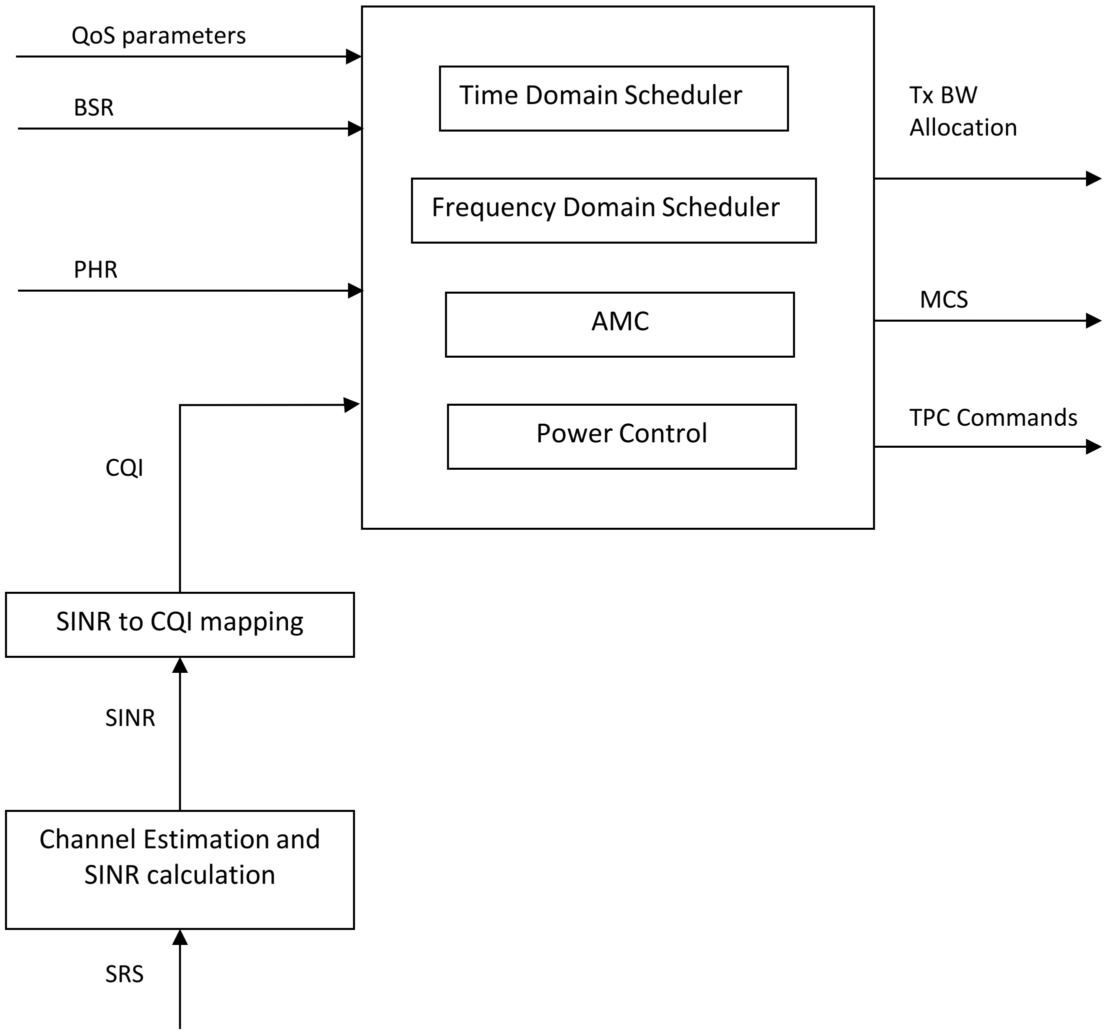
SC-FDMA Contiguity Constraint



Uplink Scheduling Constraints

- Each Transmission Time Interval (TTI) the following decisions need to be made:
  - Select UEs to transmit in this TTI
  - Allocation of Physical Resource Blocks (PRBs) to each UE
  - Transport format and maximum power for each UE to transmit
- These decisions are subject to the following constraints
  - Contiguous PRB allocation for each UE
  - Respecting QoS requirements
  - Maximizing throughput
  - Minimizing inter-cell interference

Problem Definition



System Model

System model – closed loop power control

- $P_{PUSCH} = \min\{P_{max}, 10 \cdot \log_{10} M + P_0 + \alpha \cdot PL + \delta_{mcs} + f(\Delta_i)\}$ [dBm] *JE power class.*
- *M is the number of physical resource blocks (PRB).*
- *P0 is cell/UE specific parameter signaled by radio resource control (RRC). (-81 dBm/Hz)*
- α is the path loss compensation factor. It is a 3-bit cell specific parameter in the range [0 1] signaled by RRC. (0.8)
- *PL is the downlink path loss estimate. It is calculated in the UE based on the reference symbol received power (RSRP).*
- *δmcs is cell/UE specific modulation and coding scheme defined in the 3GPP specifications for LTE.*
- *f (Δi) is UE specific. Δi (TPC) is a closed loop correction value and f is a function that permits to accumulate or use absolute correction value.*

System model - Assumptions

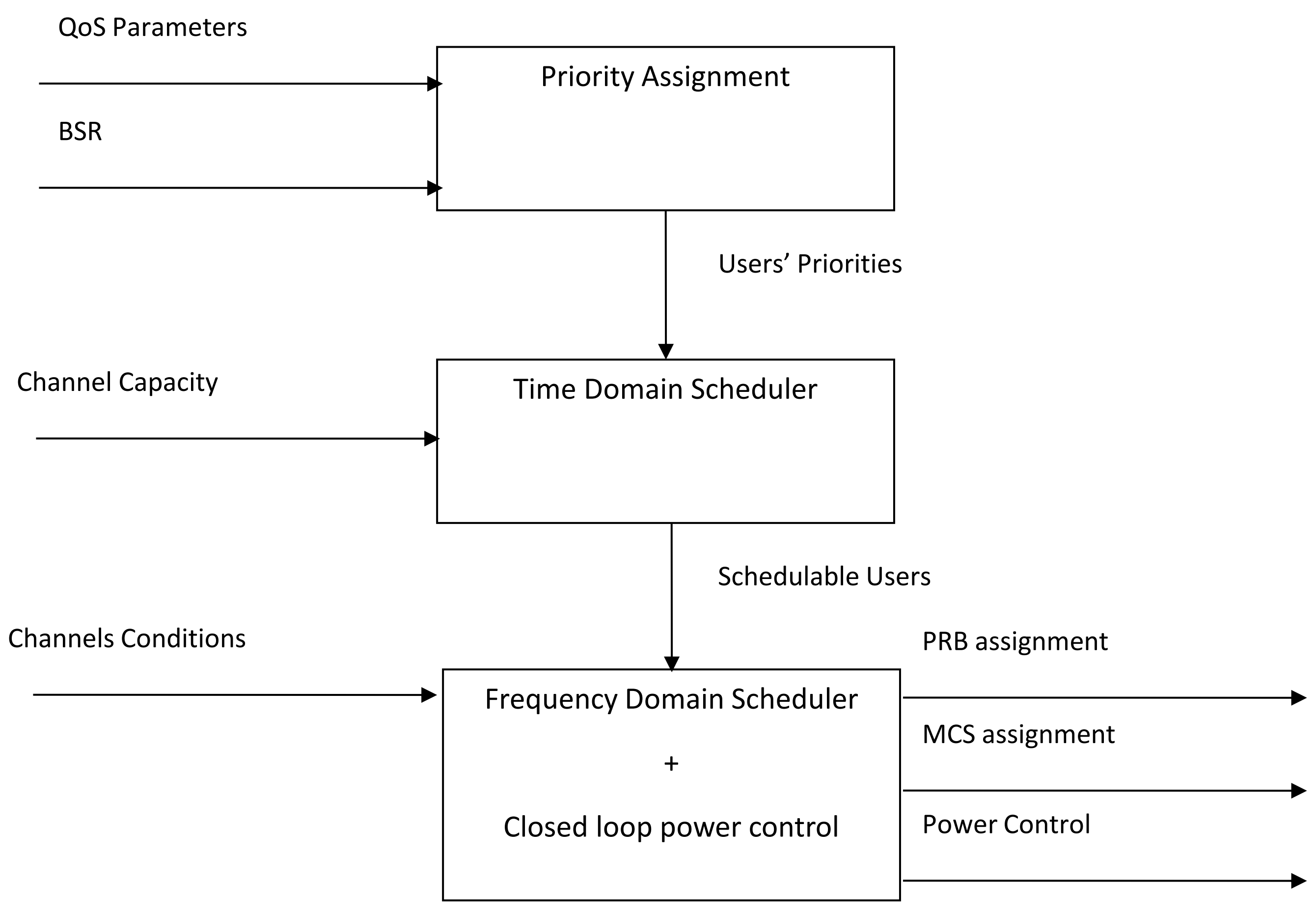
- Perfect channel knowledge is assumed with no delay to calculate Channel Quality Indicator (CQI)
- UE transmission power used in interference calculation is obtained from the reports sent by the UE to the eNB
- Assume 4 different QoS classes
- Each user has only one connection
- State of queues at UE is obtained through Buffer Status Reports (BSR) sent by UE to eNB. We assume perfect knowledge of the queues' status

Traffic Classes

- VoIP
  - Max Delay 100 msec
  - QoS 1
- Interactive Gaming
  - Max Delay 50 msec
  - QoS 2
- Video Streaming
  - Max Delay 300 msec
  - QoS 3
- FTP (Best Effort)
  - Max Delay 300 msec
  - QoS 4

Proposed Framework

Proposed Framework



Proposed Framework

- The framework solves the uplink scheduling problem via three main stages.
  - **Time domain scheduling**: selects set of users to be served according to their given priority
  - **Frequency domain scheduling**: performs PRB allocation, initial power allocation and MCS selection
  - **Closed loop fractional power control**

Time Domain Scheduling

$$P_i = V_i(S_i(m)) + \frac{QoS_i}{8}$$

$$V_i(s_i(m)) = \frac{1}{1 + e^{-q_i\left(S_i(m) - B_i^{max}\right)}}$$

$$B_i^{max} = TrafficSourceRate_i * D_i^{max}$$

- QoS_i is the quality of service class
- Division by 8 is done to have the QoS part comparable to the delay part
- D_i^{max} is the maximum allowable delay
- $S_i(m)$ is the queue length of user *i* at frame *m*

Frequency Domain Scheduling

- PRB group: set of empty contiguous PRBs
- Search for the PRB group or subset thereof that would meet the user's requested bytes with the least number of PRBs
- Assuming maximum power is used for transmission the appropriate MCS is selected
- Transmission power is then recalculated from MCS and number of assigned PRBs according to closed-loop power control loop while meeting interference limit (next slide).
- More iterations can be done. However, a stable power typically reached using only one.

Closed Loop Fractional Power Control

- Set limit for interference generated by a cell CIL (Cell Interference Limit)
- Map overall CIL to individual UE interference limits
- Approaches to dividing CIL on users
  - Equal weights
  - Low weight – High path loss (Cell Edge)
  - Low weight – Low path loss (Cell Center)

$$IL_i = \frac{CIL * w_i}{\sum_k w_k}$$

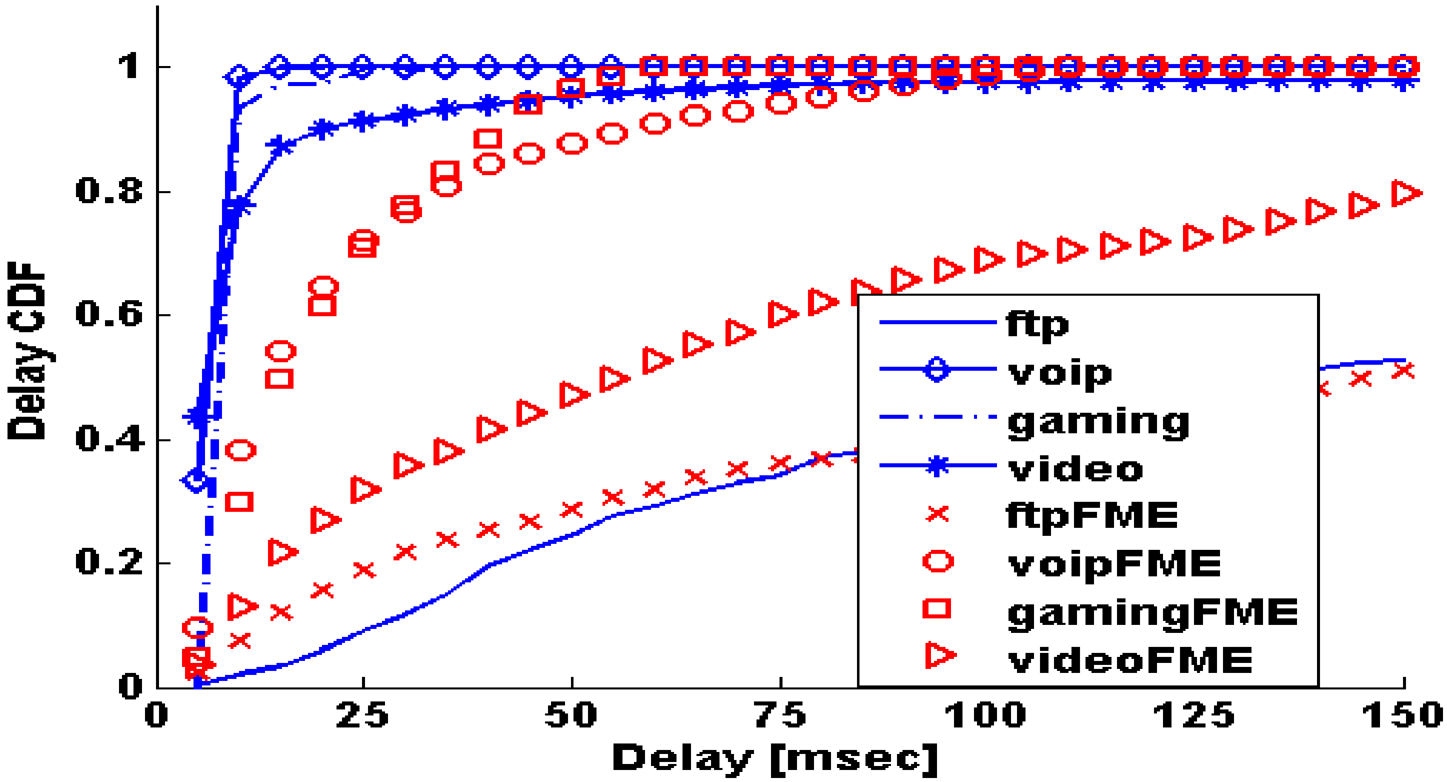
Performance Evaluation and Results

System Model

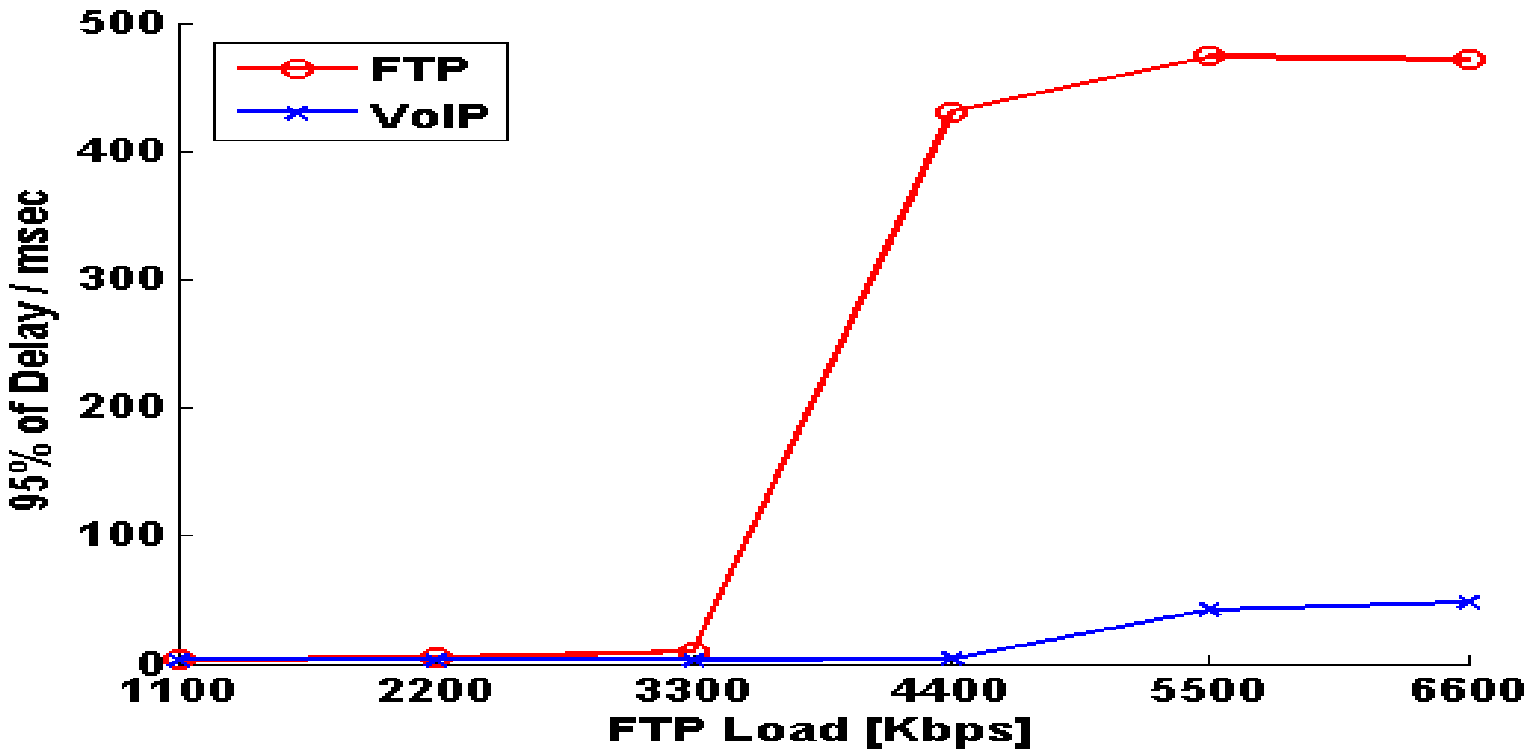
Parameter	Setting
System Bandwidth	10MHz
Channel Model	Winner II C1- Suburban Macrocell
User Speed	60m/sec
TTI	1 ms
Number of OFDM symbols per slot	7
Noise Power	-160 dBm/Hz
Rx Noise Figure	5 dBm
Maximum User Power	24 dBm

- Number of users: 100.
- Four traffic classes: VoIP, FTP, Interactive Gaming, Video Streaming
- Proposed scheme compared to the First Maximum Expansion (FME)
  - Delay
  - Throughput
  - Generated interference.

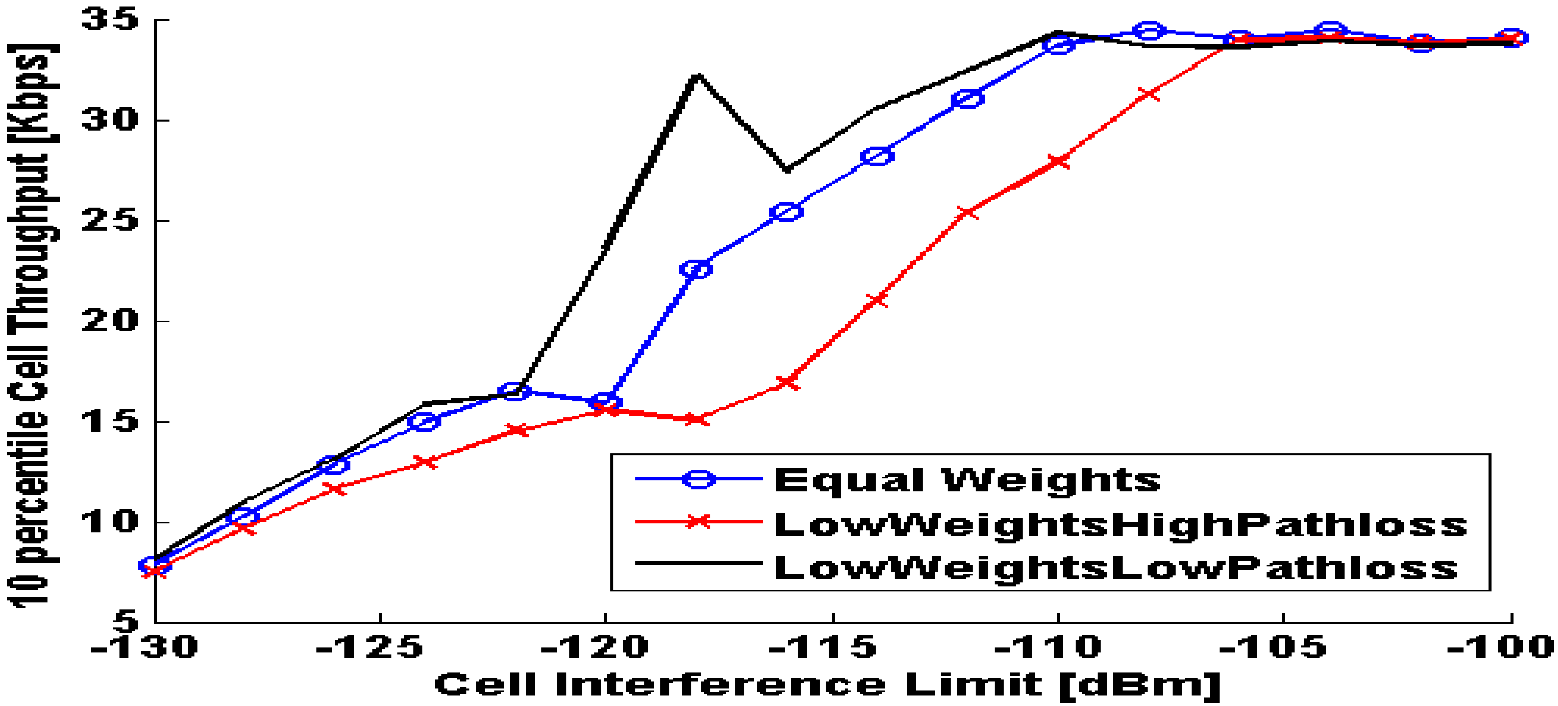
Performance Evaluation – Delay CDF



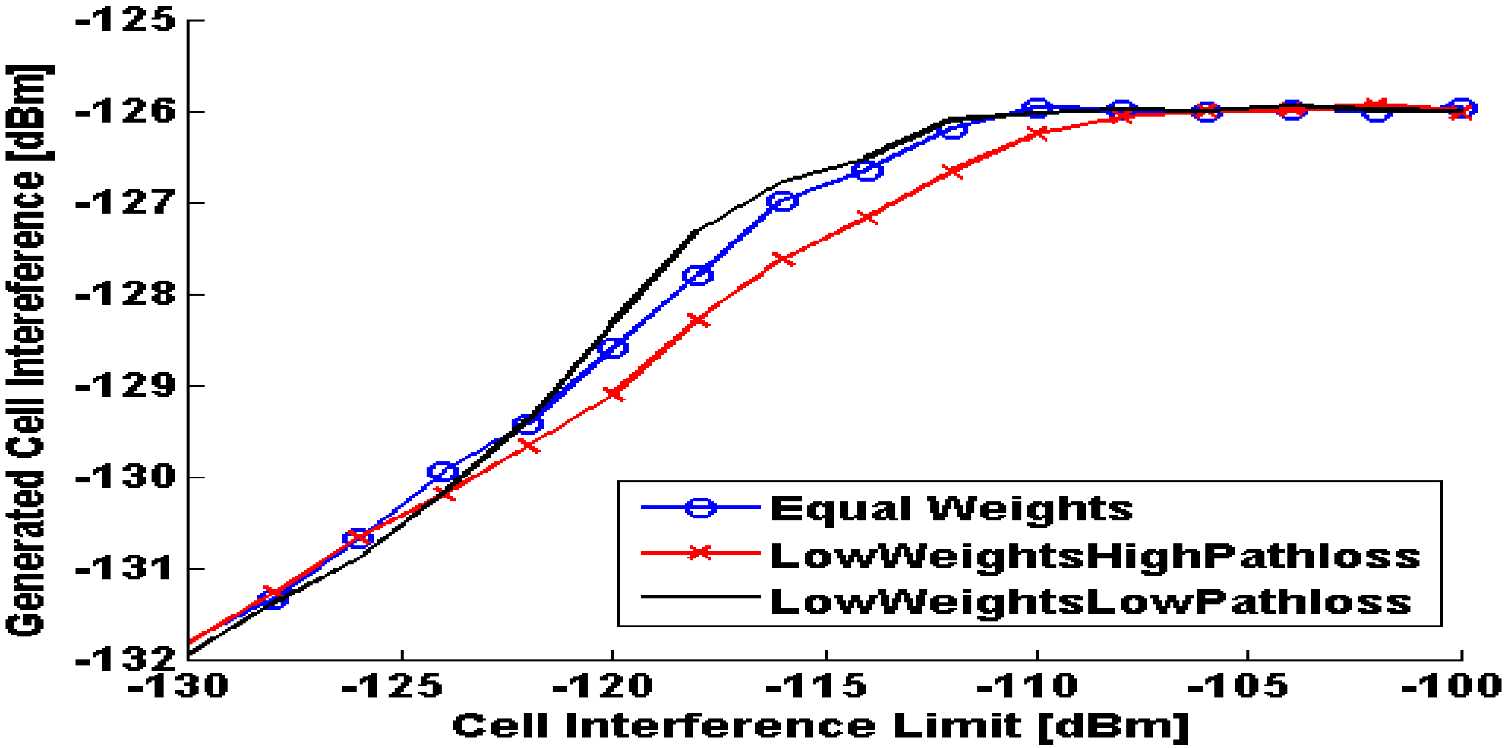
Performance Evaluation – Delay vs Load



Performance Evaluation – Cell edge Throughput



Performance Evaluation – Generated Interference



Conclusions

- Combining channel dependent scheduling, AMC and power control.
- QoS requirements consideration in the scheduling decision.
- Tradeoff between
  - PRB allocation and power allocation
  - Maximizing throughput and minimizing interference.
- Scheme is capable of achieving QoS differentiation and meeting interference limits.
- Better performance in terms of delay, packet drop ratio, and generated interference with the expense of small decrease in throughput

- **Future work** includes evaluation in mutli-cell environments.

Questions

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