End-to-End Throughput Metrics for QoS Management in 802.16j MR Systems

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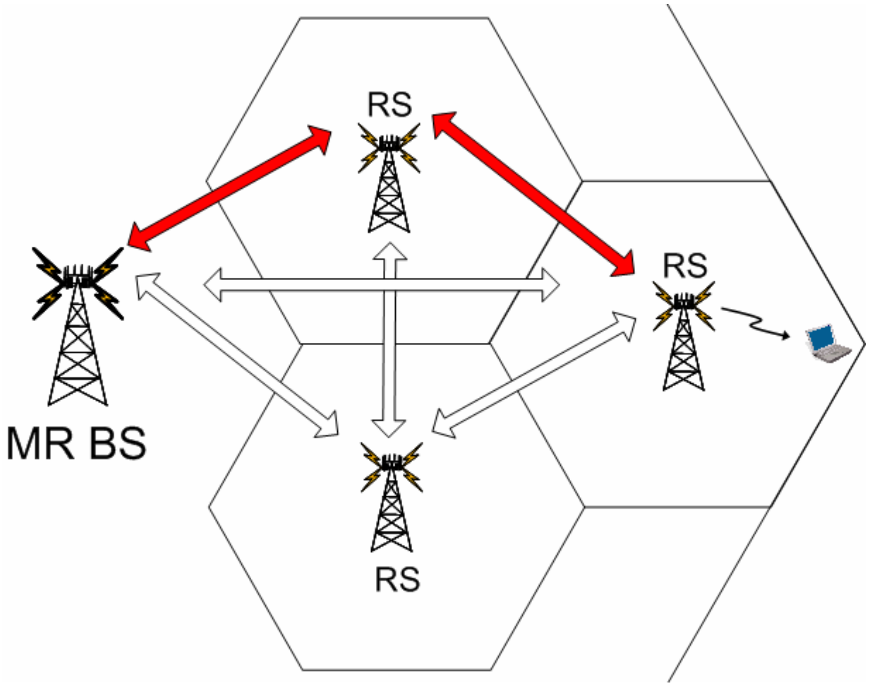
Purpose:

To propose throughput metrics for end-to-end QoS management

End-to-End Link Quality Tracking



• MR BS needs to keep track of link qualities (end-to-end QoS) over multi-hop routes – these depend on physical channel conditions over different hops (OFDMA PHY)

• **Goal:** Design PHY abstraction metrics to minimize feedback overhead complexity

Summary of Contribution

- Propose a methodology to estimate end-to-end quality of a multi-hop communication link at the MMR BS:
- Quality of Service (QoS) Metrics

  => Mean end-to-end throughput

  => Mean end-to-end delay
- Approach 1: Compute the harmonic mean of the capacities (only depends on SINR) over individual wireless links.
- Approach 2: Compute the harmonic mean of achievable throughputs (accounting for link errors, finite MCSs, overheads etc.) over individual wireless links may be computed.
- The second approach is also equivalent to the summation of the expected transmission time (ETT) over each hop.

End-to-End PHY Abstraction for a Multi-hop Route

- An end-to-end throughput metric can be mapped to each established multi-hop route; which can be calculated as:

$$End\_to\_End\_Throughput = \left(\sum_{n=1}^{N} \frac{1}{Per\_Link\_Throughput\_over\_Hop\_n} \right)^{-1}$$

- This formula assumes orthogonal resource sharing (in time or frequency) among hops in a given routing path.
- Benefit 1: Such a PHY abstraction metric informs MMR BS about the overall quality of the multi-hop route in an end-to-end sense and allows for quick decision making, e.g. establish a new route if the link quality falls below the desired end-to-end QoS level.
- Benefit 2: Several centralized functionalities coordinated by MMR BS (e.g. scheduling algorithms, routing algorithms, latency management, other MAC and higher layer functions) can utilize from this end-to-end PHY abstraction metric.
- **Any per-link PHY abstraction metric can be used** on each hop to store PER vs. SINR tables (e.g. mean capacity, EESM etc.)

Possible Per-Link PHY Abstractions

- PHY abstractions enable to reduce the vector of SNR values to a small set of parameters, which can be used to approximate link layer performance.
- Mean-capacity (proposed for 802.11)

$$\log_2(1+SINR_{eff,n}) = \frac{1}{K}\sum_{k=1}^{K}\log_2(1+SINR_{n,k})$$

$$\Rightarrow SINR_{eff,n} = 2^{\frac{1}{K}\sum_{k=1}^{K}\log_2(1+SINR_{n,k})} - 1$$

- Exponential effective SINR mapping (EESM) (proposed for 3G)

$$SINR_{eff,n} = -\beta\log\left(\frac{1}{K}\sum_{k=1}^{K}\exp\left(-\frac{SINR_{n,k}}{\beta}\right)\right)$$

Capacity-based End-to-End PHY Abstraction

$$C = \frac{1}{\sum_{n=1}^{N} \frac{1}{C_n}} = \frac{1}{\sum_{n=1}^{N} \frac{1}{\log_2(1 + SINR_{eff,n})}}$$

C ⇒ End-to-end capacity

C_n ⇒ Effective capacity over hop n=1,…,N

$SINR_{eff,n}$ ⇒ Effective SINR over hop n (can be computed using any PHY abstraction; e.g. mean capacity, EESM etc.)

N ⇒ Number of hops over the established route between BS and SS

Throughput-based End-to-End PHY Abstraction

- ETT is a metric used for routing in 802.11s mesh standard.
- For a packet of B bits, end-to-end latency T and end-to-end throughput R are related to each other:

$$Throughput = \frac{B}{T} = \frac{B}{\sum_{n=1}^{N} ETT_n}$$

- Formula for cost per link:

$$ETT_n = \left[T_{ovrhd} + \frac{B}{R_n} \right] ETX_n$$

ETX_n : Expected number of packet transmissions until successful reception over hop subject to instantaneous channel conditions (accounting for HARQ)

R_n : Aggregate data rate per packet over hop based on the MCS chosen by the link adaptation algorithm while satisfying a certain target packet error rate (PER) subject to instantaneous channel conditions

B : Number of bits per packet

T_{ovrhd} : Latency cost per link due to fixed channel access and protocol overheads

Related References on End-to-End Analysis

[1] O. Oyman and S. Sandhu, “Throughput Improvements in Micro-cellular Multi-hop Networks”, 802.16 MR Study Group Contribution, Nov. 2005

[2] O. Oyman and S. Sandhu, “A Shannon-Theoretic Perspective on Fading Multi-hop Networks”, Proc. CISS, Princeton, NJ, March 2006

[3] O. Oyman, “Reliability Bounds for Delay-Constrained Multi-hop Networks”, Proc. Allerton Conference, Monticello, IL, Sep. 2006

[4] O. Oyman, “End-to-End Throughput and Latency Measures for Multi-hop Routing in Relay-Assisted Broadband Cellular OFDM Systems”, Proc. IEEE Radio and Wireless Symposium (RWS), Long Beach, CA, Jan. 2007.