Project	**IEEE 802.20 Working Group on Mobile Broadband Wireless Access** <**http://grouper.ieee.org/groups/802/20/**>
Title	**Expectations on Spectral Efficiency, Throughput, and Other Performance Metrics**
Date Submitted	**2004-03-01**
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Re:	IEEE 802.20 WG on MBWA Call for Contributions: Session # 7 - March 15-19, 2004
Abstract	This contribution summarizes various performance metrics, such as spectral efficiency and throughput, for various air interface technologies in the context of expected performance with a new air interface.
Purpose	The purpose of the contribution is to addresses the question of how much performance improvement in spectral efficiency and throughput can be expected over current technologies.
Notice	
Release	
Patent Policy	

Contribution C802.20-04/49

Expectations on Spectral Efficiency, Throughput, and Other Performance Metrics

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Topics

- Next Generation Capability
  - Improvement factors
  - Order-of-magnitude cost reduction
- Spectral Efficiency
- Latency

Improvement Factors

- Order of magnitude cost reduction
- “Ubiquitous” coverage
- User experience
  - Ease of use
  - Installation
  - Reliability

Cost Improvement: Goal of 10X

- **Factor: (Deployment + Operating)/Capacity**

- **Deployment cost**
  - System acquisition (H)
    - Capacity impact (H)
  - Access Terminal cost (M)
  - Site development (L)
    - Footprint
    - Power access
    - Government fees & civil engineering
    - Tower + antenna
  - Backhaul access (L)
    - Sized to peak loading
    - FE/GE is not “free”
    - Wireless backhaul is unreliable
      - Wireless backhaul so far has not made impact
- **Operating cost (L)**
  - Commercial power
  - Maintenance
  - Site lease

Cost Impact Example: 802.11

- **Cost of Access Terminal, Access Point**
  - Dropped by 80-90% since introduction
  - Lower cost components
  - Improved manufacturing efficiencies & volume
  - Ease of installation
- **Impact of Standard**
  - Improved multi-user access experience
  - 2-to-54 Mbps peak rates
  - Proven protocol experience
- **Area 802.11 coverage cost >3X macro-cellular cost**

The 802.11 standard itself had little impact on "cost" other than to provide an open, broadband, widely-accepted interface

Capacity Limit

- **Shannon limit**

$$C = W \cdot \log_2\left(1 + \frac{S}{N}\right)$$

- **Fundamental constraint**
  - **Independent of channel coding**
  - **Independent of modulation**
- **Implementation margin ~ 0.5 dB**
  - **Turbo codes**
  - **Low density parity codes (LDPC)**

Spectral Efficiency

- Mean spectral efficiency (bits/sec/Hz)

$$\langle C \rangle = \left\langle \log_2 \left(1 + \frac{S(R_j, \sigma_k)}{N(R_j, \sigma_k)} \right) \right\rangle$$

- S = Receiver input signal power
  = (Tx Pwr) x (Tx Ant Gain) x (Path Loss)
- N = Receiver input noise power
  = N_{PA} x G_A x L(R,S) x B + (N_{TH} + I_o) x NF x B
- L = Path loss per M.1225 vehicular model
  $\cong 40*\log_{10}(R)-18\log_{10}(H_B)+21\log_{10}(F)+80+\sigma$

Parameters

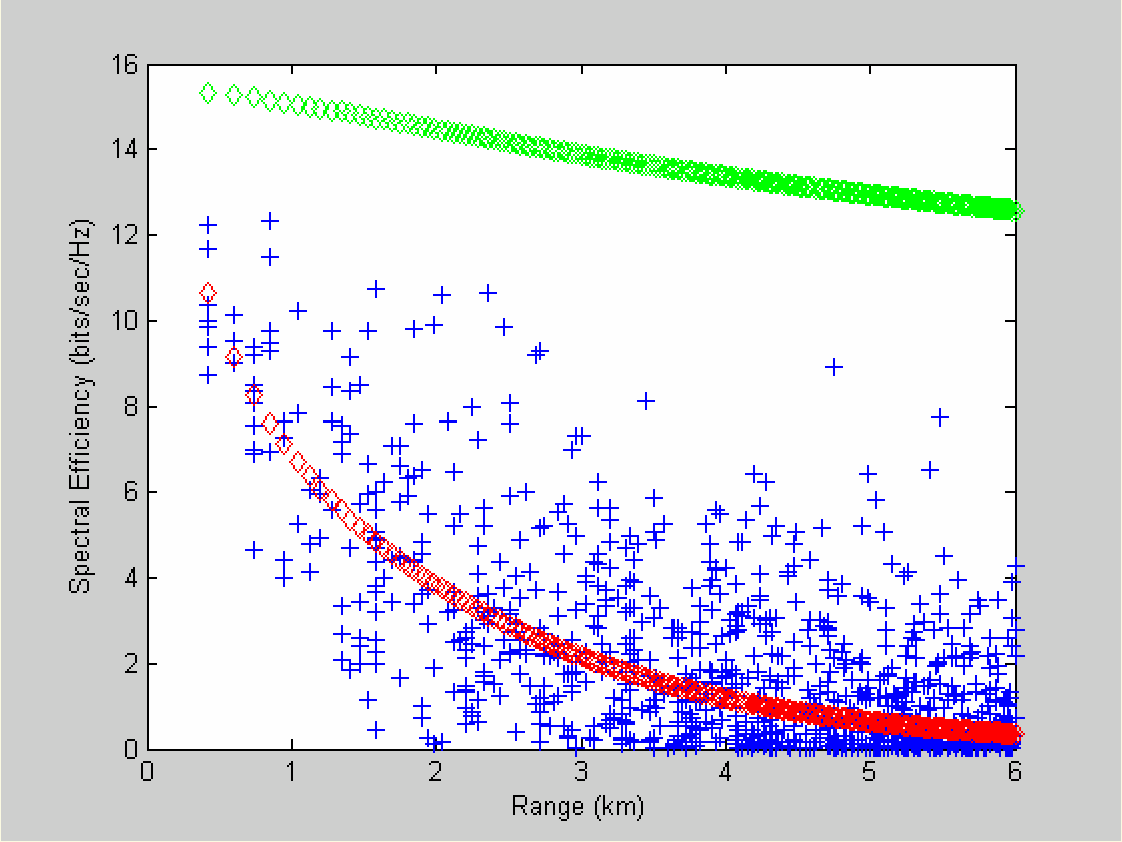
- N_{PA} = PA noise floor = 60 dB below output
- N_{TH} = thermal noise = -174 dBm
- I_o = interference = 3 dB greater than N_{TH}
- NF = receiver noise figure = 8 dB
- B = noise bandwidth = 3.8 MHz
- W = channel bandwidth (5 MHz)
- R = range (km)
- H_B = BTS antenna height (m) = 25 meters
- F = frequency (MHz) → 2100
- σ = log-normal distribution (std dev= 10 dB)
- M = implementation margin = 3 dB

Spectral Efficiency Limits

Spectral efficiency versus range in log-normal environment

Free-Space:
<C>=13.7 b/s/Hz

Log-normal:
<C>=2.1 b/s/Hz
Cell = 6 km



- ♦ **Free-space**
- ♦ **Log-normal mean**
- ✚ **Log-normal scatter**

Spectral Efficiency Recommendation

- 10X increase over current systems exceeds Shannon limit
- 1 b/s/Hz represents level of existing standards

The minimum spectral efficiency shall be 2 b/s/Hz on the forward link in a vehicular environment defined by ITU M.1225 for a cell range of 6 km.

IEEE C802.16e-03/22r1

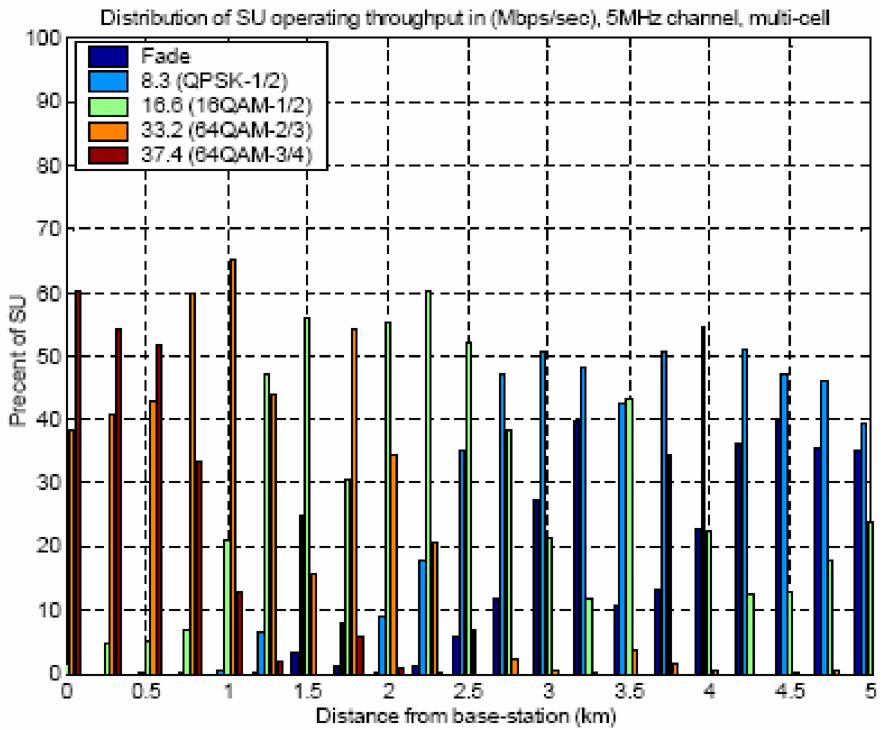


Figure 16: Distribution of SS throughput in the cell, vehicular (M.1225, optimized for better coverage)

The average capacity per sector is 1.35 Bit/sec/Hz, and for the entire cell it is 2.71 Bit/sec/Hz. Performance values below 0.1Bit/sec/Hz are marked in black as non-covered.

Current Performance

IEEE802.20 needs to be better than:

	W (MHz)	B (Mbps)		C (b/s/Hz)
TD-CDMA (Rel. '99)	5	**FWD**	**REV**	**FWD**
Peak rate (no uplink)		5	-	
Peak rate (3:1 TDD split)		~3.4	~1.1	
Avg throughput per sector		1.5	~0.9	**1.2**
TD-CDMA (Rel. 5)	5	**FWD**	**REV**	
Sector throughput		1.9		**1.52**
EVDO	5	**FWD**	**REV**	
Peak		2.4	0.153	
Throughput		0.7		
Throughput @ 3 km/h, 1 Rayleigh path		1.2		**0.96**
Enhanced DO (proposed)	5	**FWD**	**REV**	
Peak		~3	~1.2	
IEEE 802.16a (non-mobile)				
Peak (3:1 TDD split)	20	60	10	

Latency Constraint

- **Purpose: Illustrate impact of PHY/MAC round-trip-delay on TCP throughput**

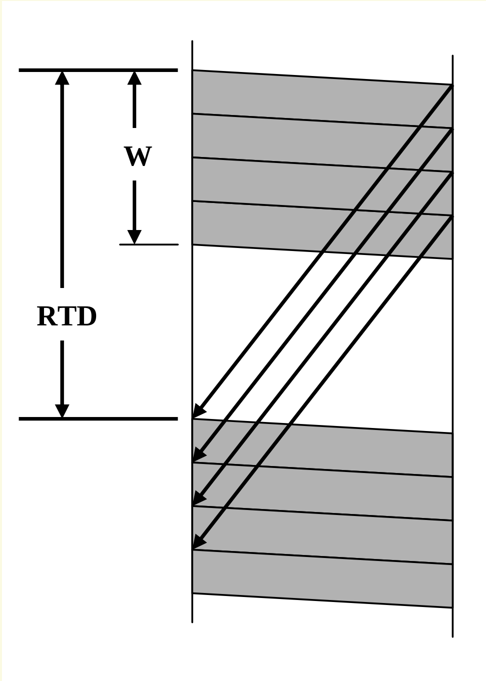
- **Estimate throughput boundary for *error-free* transmission**

Latency Constraint

- Flow control where RTD is greater than the TCP window transmit time
- Maximum achievable TCP throughput:

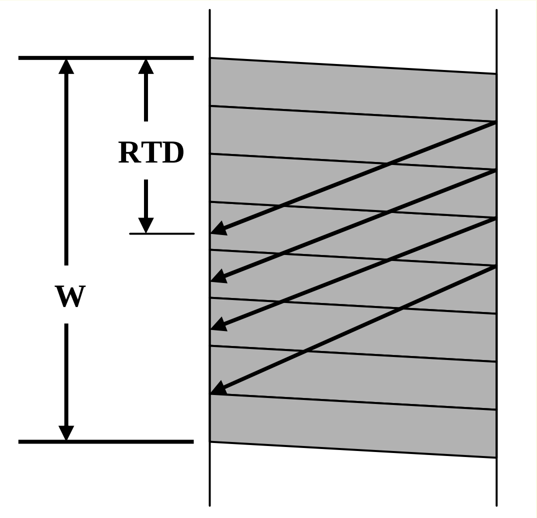
$$R_{\max} = \frac{W * S}{RTD}$$

where	W	= TCP window size
	S	= TCP segment size
	RTD	= Round Trip Delay



Latency Constraint

- Window flow control case where the round trip delay time (RTD) is less than the time required to transmit the window.
- Source is capable of transmitting at the full rate supported by the transmission medium (RM) and flow control is not active.
- With error-free transmission on the RLP link, the round-trip delay is given by:

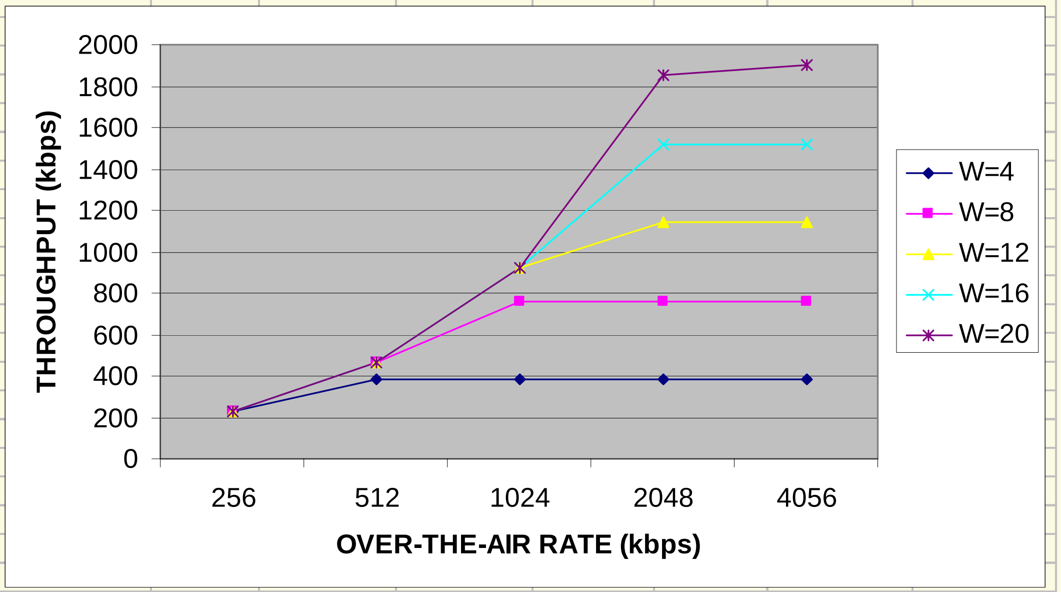


$$RTD = 2 \cdot \left(D_I + D_R\right) \quad (2)$$

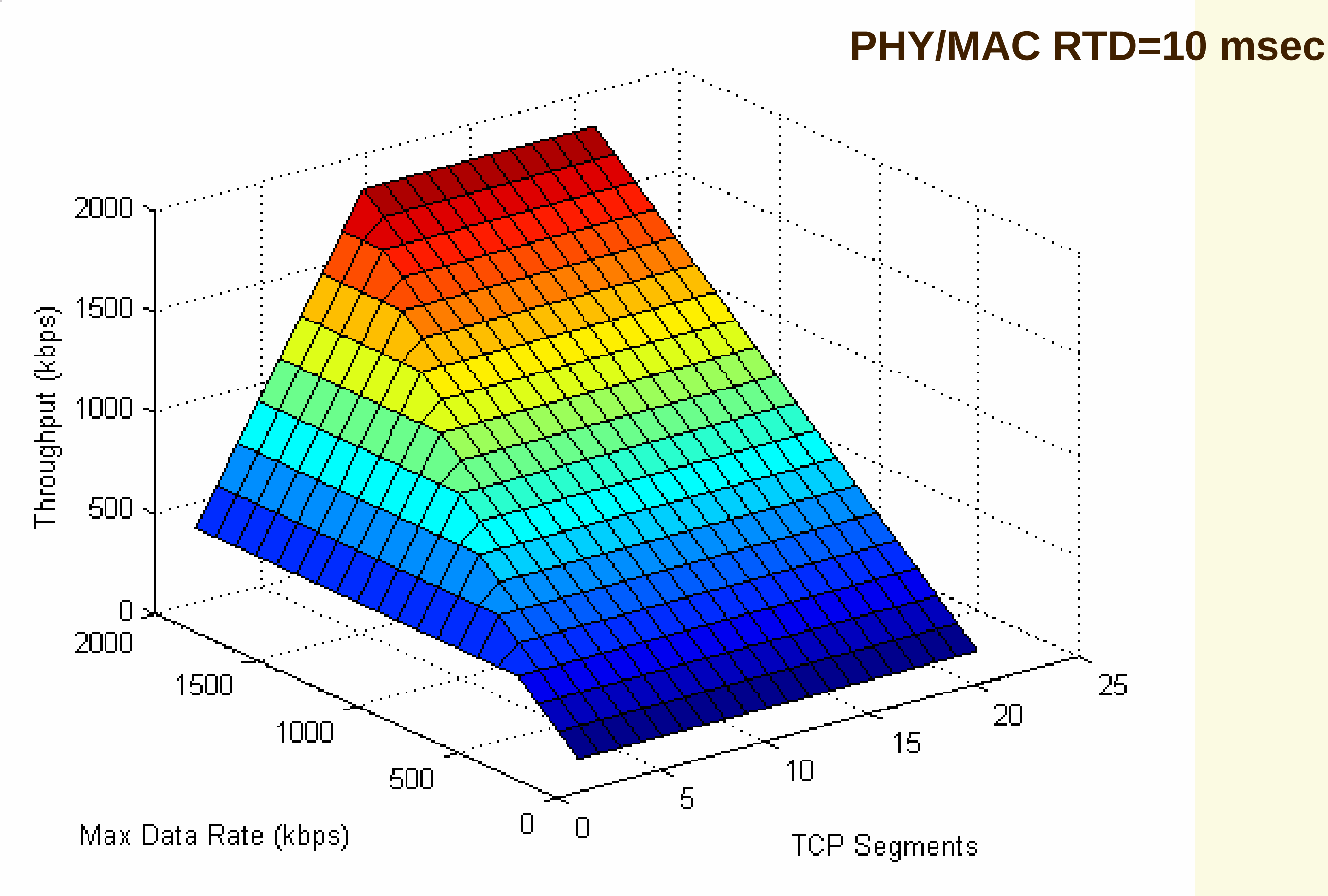
  - DI = internet delay
  - DR = one-way PHY/MAC delay

Latency Constraints

TCP Segment Size (bytes)	1500
Internet Delay (ms)	50
One-way radio link latency (ms)	10
RLP NAK guard (ms)	2
RLP delay	2
PPP header (bytes)	10
RLP header (bytes)	4
RLP frame size (bytes)	44

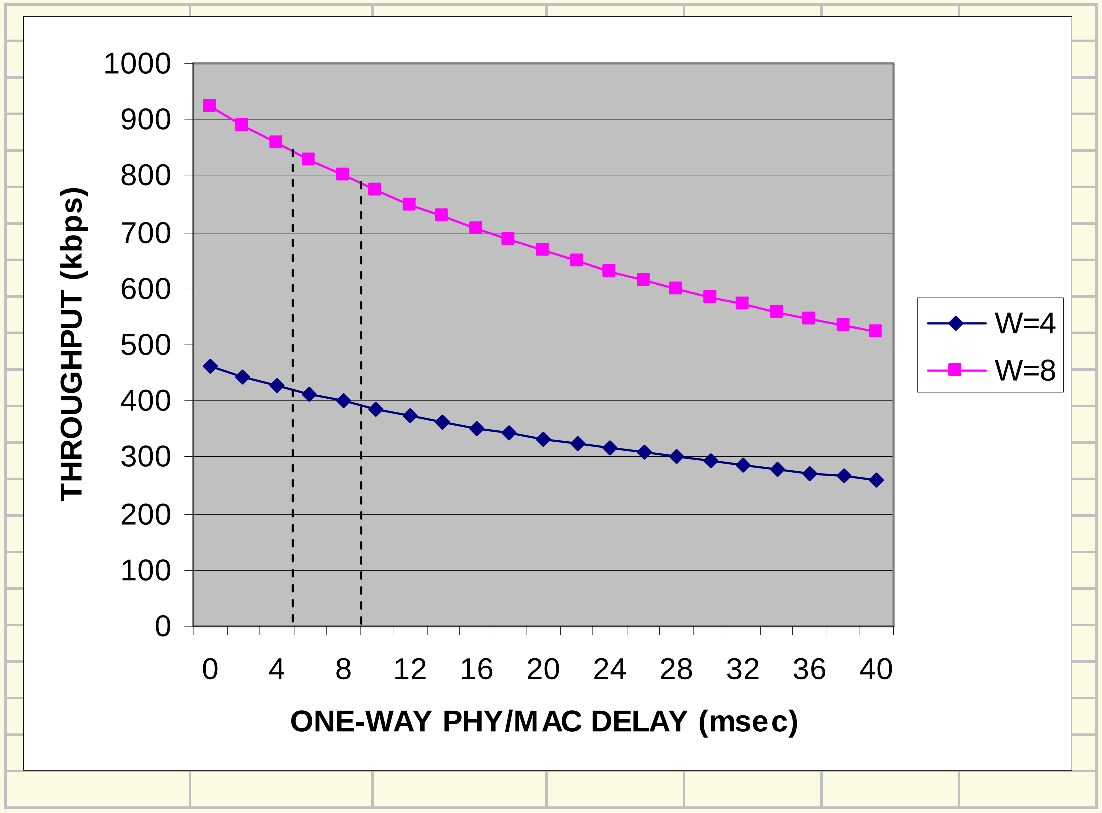


Throughput Tradeoffs



Latency Constraints

Throughput for TCP Window sizes of 4 and 8 frames versus one-way delay



Latency Recommendation

- Distinguish between “Latency” and “Round Trip Delay”
- Round trip delay for TCP traffic may adversely affect user throughput
- The MAC round trip delay should be less than 10% of the network delay

Since network round trip delay may be less than 100 msec, the round trip delay of MAC processing for TCP-based traffic shall be less than 10 msec.

END