

Project	<b>IEEE 802.20 Working Group on Mobile Broadband Wireless Access</b> < <a href="http://grouper.ieee.org/groups/802/20/">http://grouper.ieee.org/groups/802/20/</a> >	
Title	<b>Expectations on Spectral Efficiency, Throughput, and Other Performance Metrics</b>	
Date Submitted	<b>2004-03-01</b>	
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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 address the question of how much performance improvement in spectral efficiency and throughput can be expected over current technologies.	
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The image shows a spiral-bound notebook with a light brown, textured cover. The spiral binding is on the left side. The notebook is set against a dark brown background. The text is centered on the cover.

**Contribution C802.20-04/49**

**Expectations on Spectral Efficiency,  
Throughput, and Other Performance  
Metrics**

Joseph Cleveland

Anna Tee

# Topics

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## **Next Generation Capability**

- Improvement factors
- Order-of-magnitude cost reduction






## **Spectral Efficiency**



## **Latency**

# Improvement Factors

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-  **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

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## 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  
=  $N_{PA} \times G_A \times L(R,S) \times B + (N_{TH} + I_o) \times NF \times B$
- ☰ **L** = Path loss per M.1225 vehicular model  
 $\cong 40 \cdot \log_{10}(R) - 18 \log_{10}(H_B) + 21 \log_{10}(F) + 80 + \sigma$



# Parameters

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- $N_{PA}$  = 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)  $\rightarrow$  2100
- $\sigma$  = log-normal distribution (std dev= 10 dB)
- M = implementation margin = 3 dB

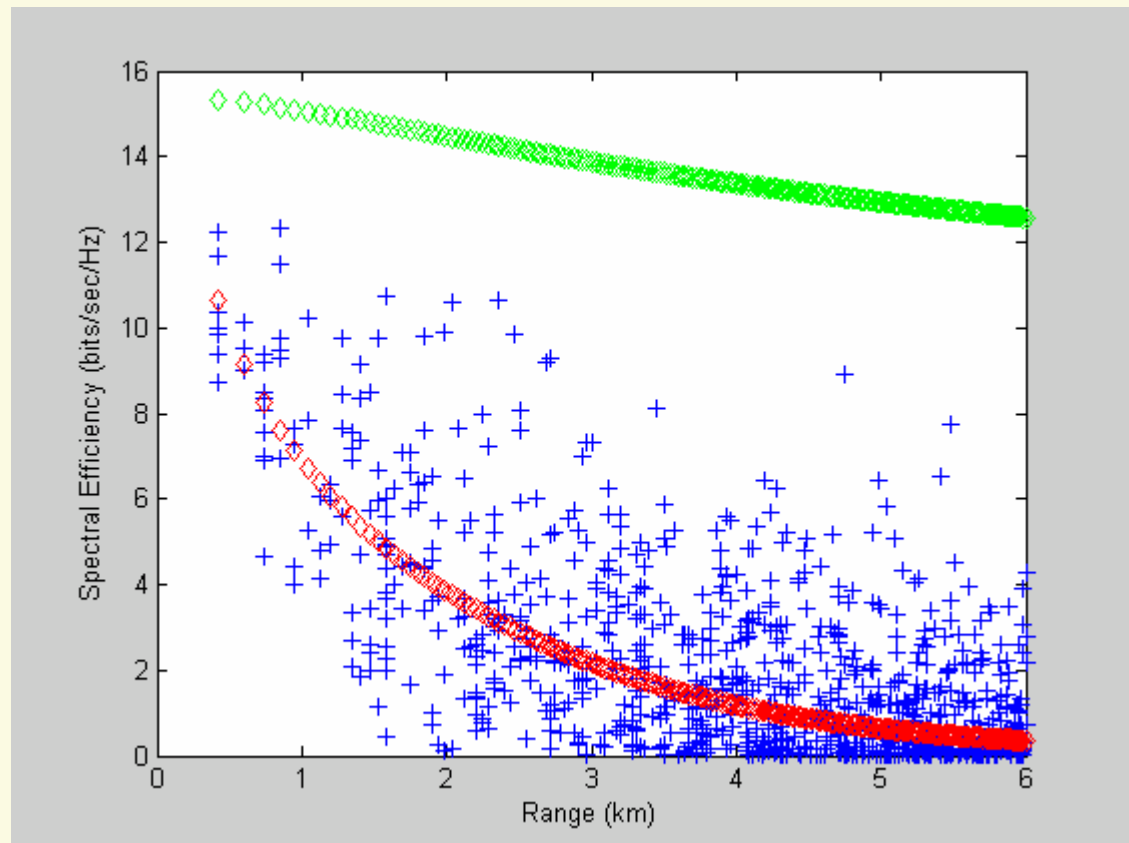
# Spectral Efficiency Limits

## Spectral efficiency versus range in log-normal environment

Free-Space:  
 $\langle C \rangle = 13.7$  b/s/Hz



Log-normal:  
 $\langle C \rangle = 2.1$  b/s/Hz  
Cell = 6 km

- ◆ Free-space
- ◆ Log-normal mean
- + Log-normal scatter



# Spectral Efficiency Recommendation

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-  **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

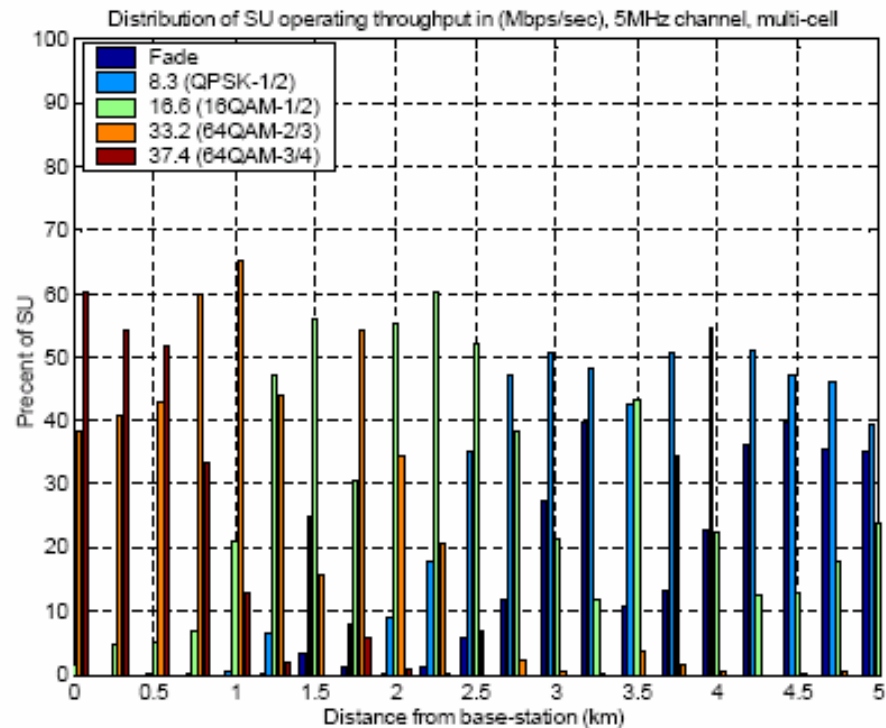


Figure 16: Distribution of SS throughput in the cell, vehicular (M.1225, optimized for better coverage)

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

# Latency Constraint

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-  **Purpose: Illustrate impact of PHY/MAC round-trip-delay on TCP throughput**
-  **Estimate throughput boundary for *error-free* transmission**

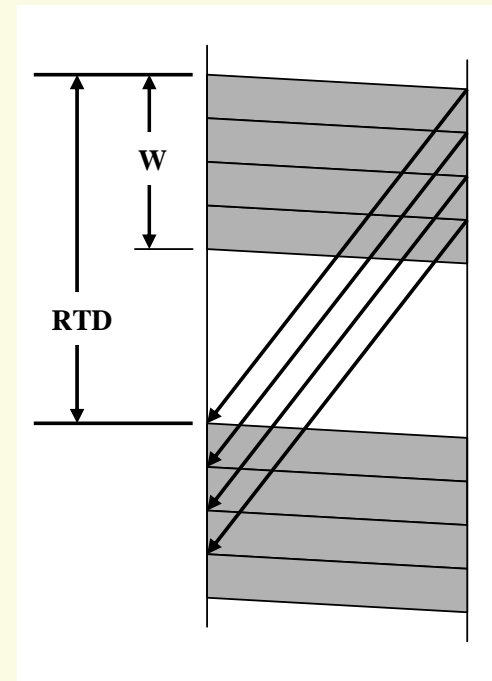
# Latency Constraint

📄 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



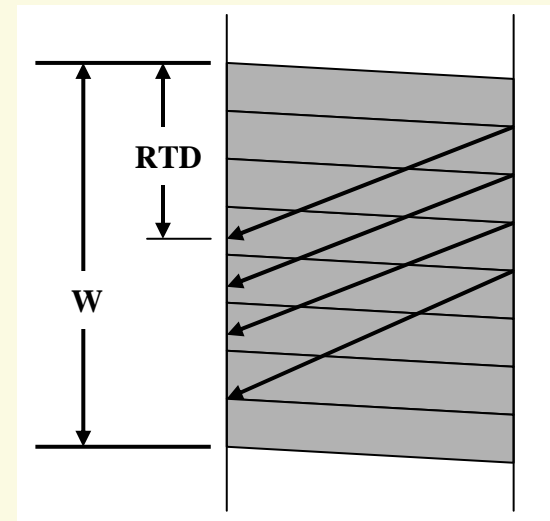
# Latency Constraint

- 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:

$$RTD = 2 \cdot (D_I + D_R)$$

- $D_I$  = internet delay
- $D_R$  = one-way PHY/MAC delay

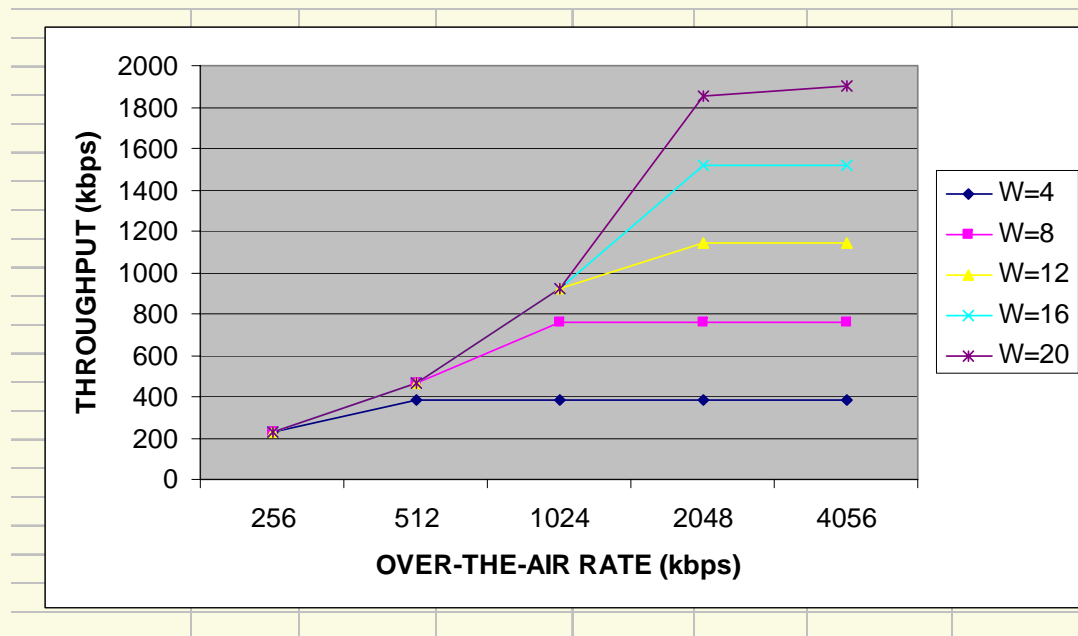
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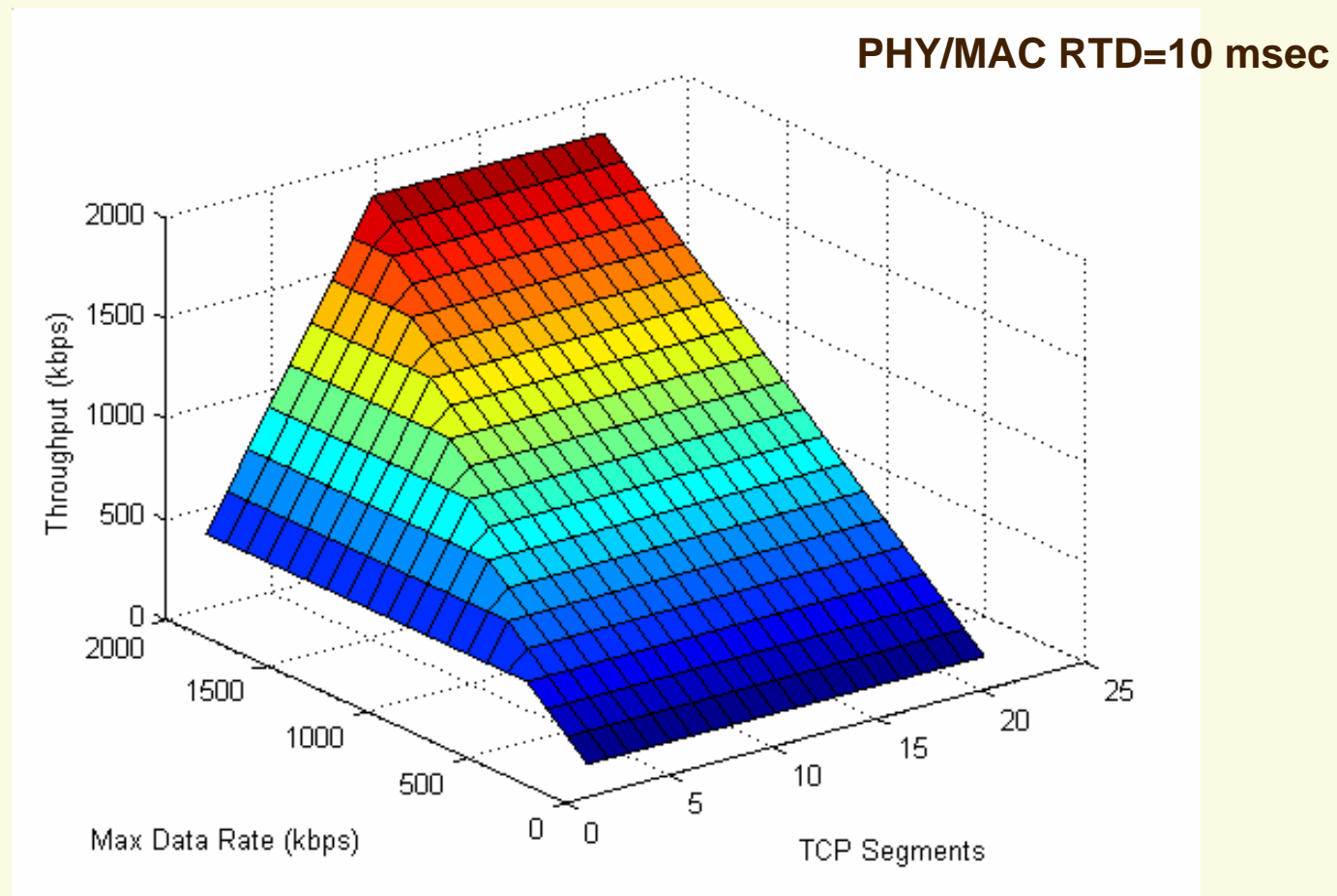


# Latency Constraints

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

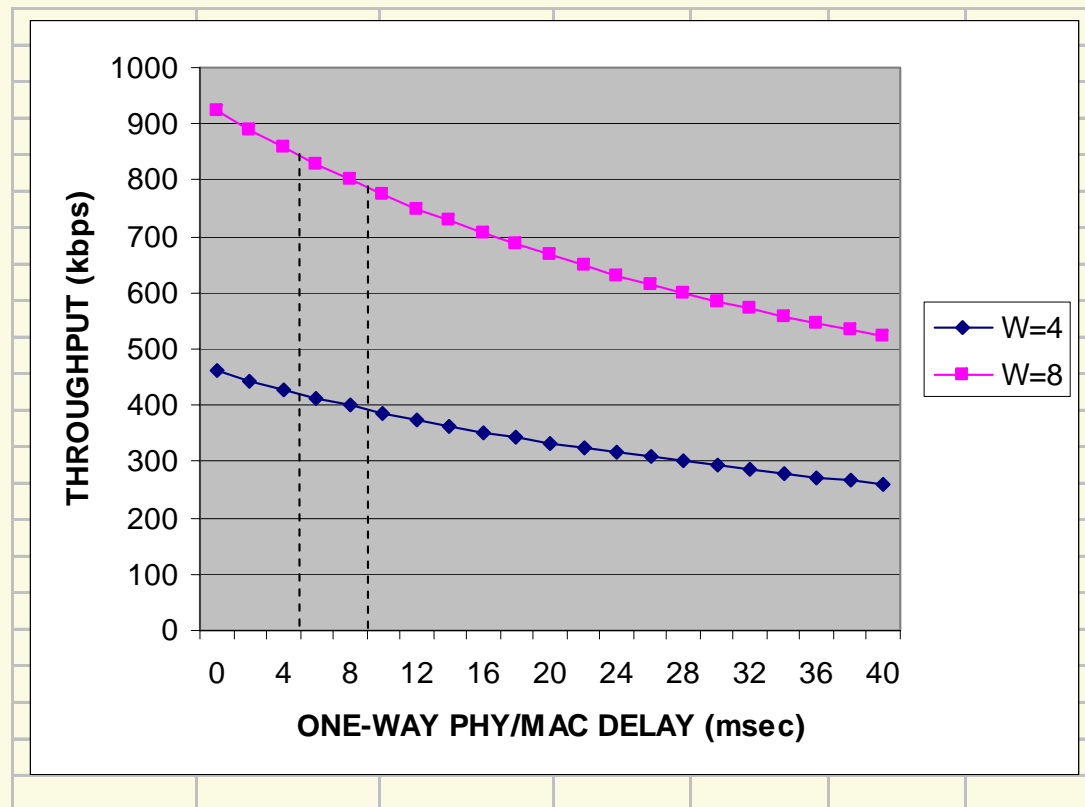


# Throughput Tradeoffs



# Latency Constraints

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



# Latency Recommendation

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- ❏ 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.**

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