Broadband Local Access

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Outline

- Motivation
- Performance experiments
- Long-term monitoring
- MAC performance
- Spectrum issues
- Conclusions

Motivation

- Determine suitability of wireless for local access
- Components
  - assess limits of technology via experimentation
    - performance (throughput and delay)
    - long-term monitoring (reliability)
  - media access layer performance
    - compare different approaches to MAC layer
    - assess capability of MAC layers to provide particular services
  - spectrum issues
    - working with under-utilized frequency bands

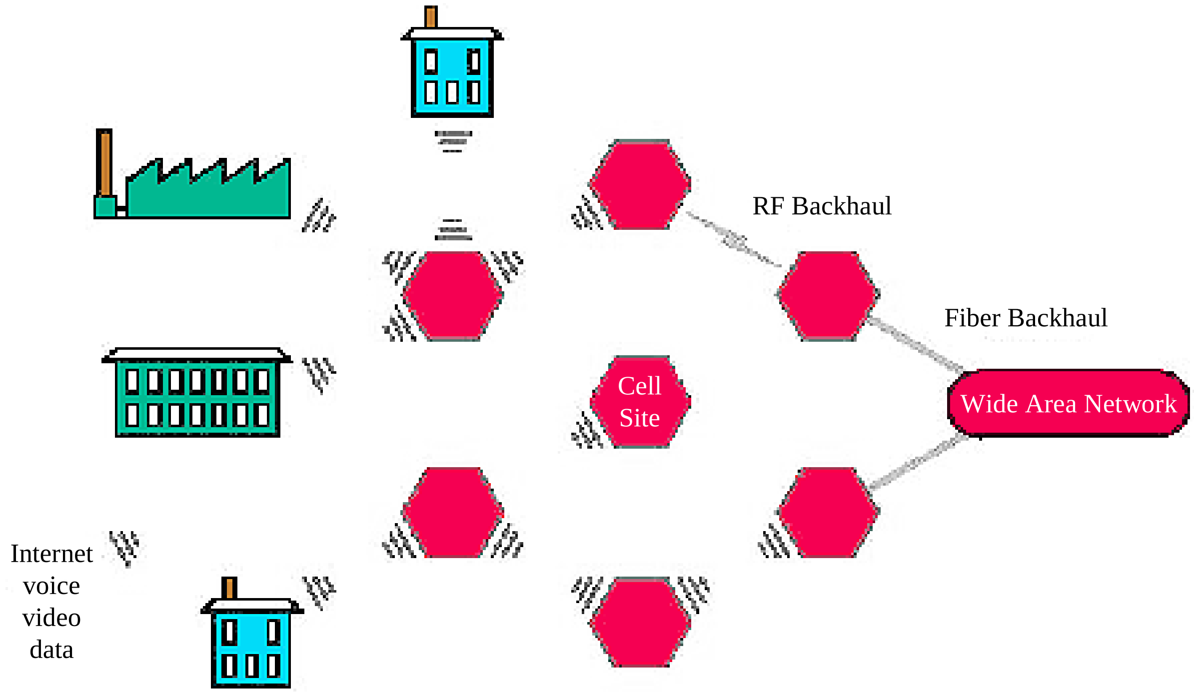
Faculty and Students

- Faculty
  - Joe Evans
  - Jim Roberts
- Students
  - Mihir Thaker
  - Harish Sitaraman
  - Jesse Davis
  - Dragan Trajkov
  - Larry Sanders
- Sprint
  - Manish Mangal (now at Sprint PCS)

Infrastructure

Experiment Infrastructure

- Prototype high bandwidth wireless solution to deliver integrated data, voice, and video services to the home or small business



Experiment Infrastructure

- Example wireless modem
  - AB-Access from Adaptive Broadband
  - 25 Mb/s shared per cellular sector in U-NII band
  - up to 256 users per sector
  - 3 km to 5 km range

Experiment Infrastructure

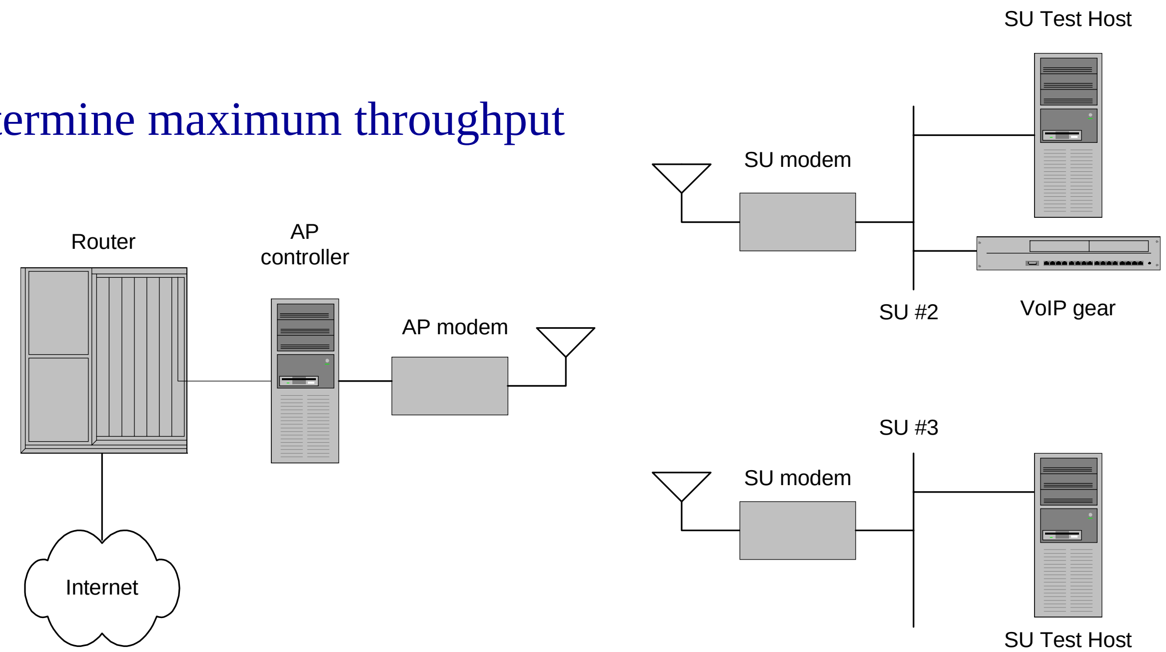
ITTC
Nichols Hall

Staff
Member's
Home

Performance Experiments

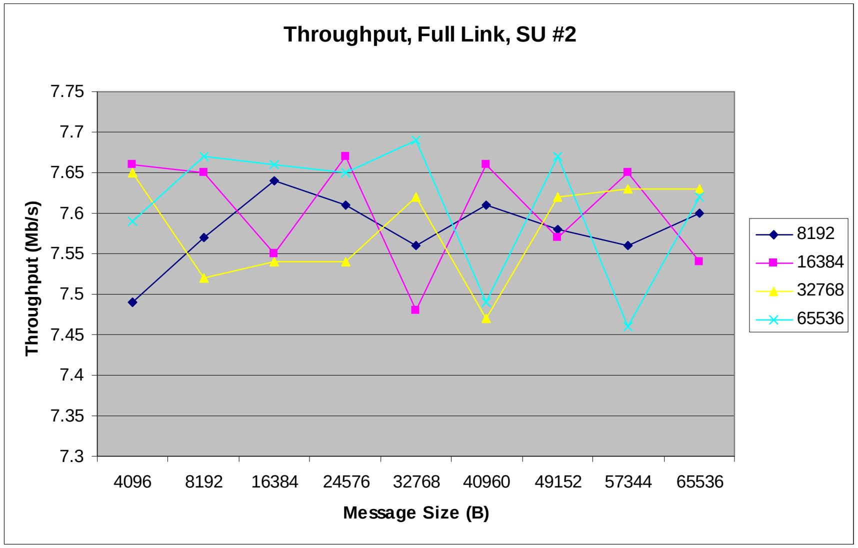
Performance Tests

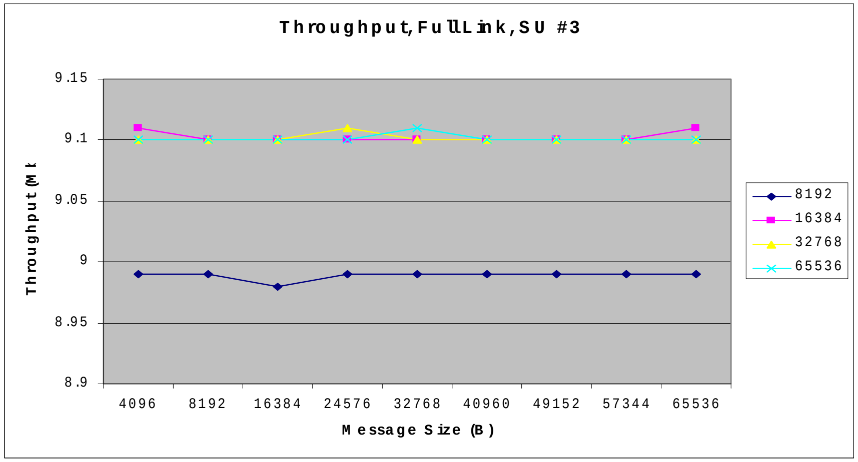
- Subscriber Unit (SU) #2 located 2.4 km from Access Point (AP), SU #3 located 10 m from AP
- NetSpec used to conduct measurement tests
  - per-host as well as aggregate bandwidth measured
  - TCP streams used for tests
- Tests performed
  - flooding of link to determine maximum throughput
  - contention tests



Performance Test Results

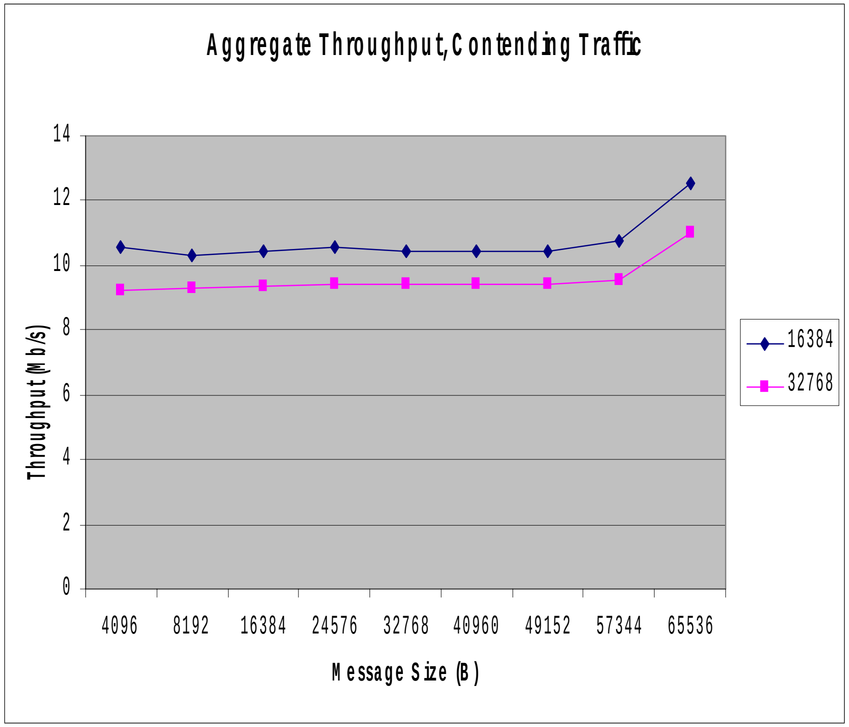
- Link flooded to determine link capacity with different buffer sizes
  - data transmitted towards and measured on AP
- Since transmitting over Ethernet from host to modem on residential side, throughput limited to less than 10 Mb/s
- Fluctuations in SU #2 bandwidth most likely due to TCP retransmits





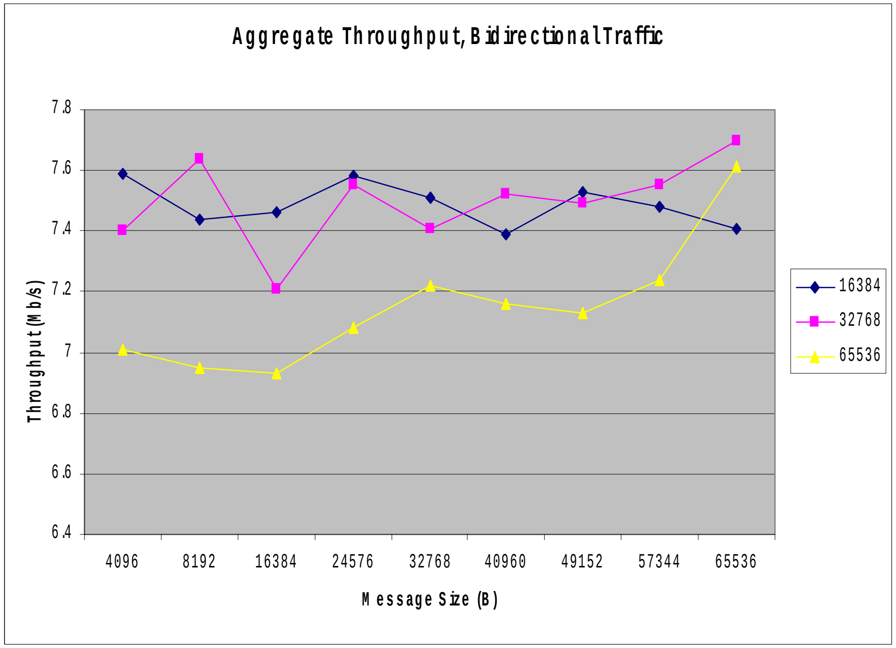
Performance Test Results

- Contention test consisted of both SUs transmitting towards AP
- Generally, SU #2 attained higher bandwidth than SU #3
- Total bandwidth about 2 Mb/s slower than predictions from vendor



Performance Test Results

- Traffic sent from both sides of link between AP and SU #2
- Since transmitting over Ethernet from host to modem on residential side, throughput limited to less than 10 Mb/s



Long-term Monitoring

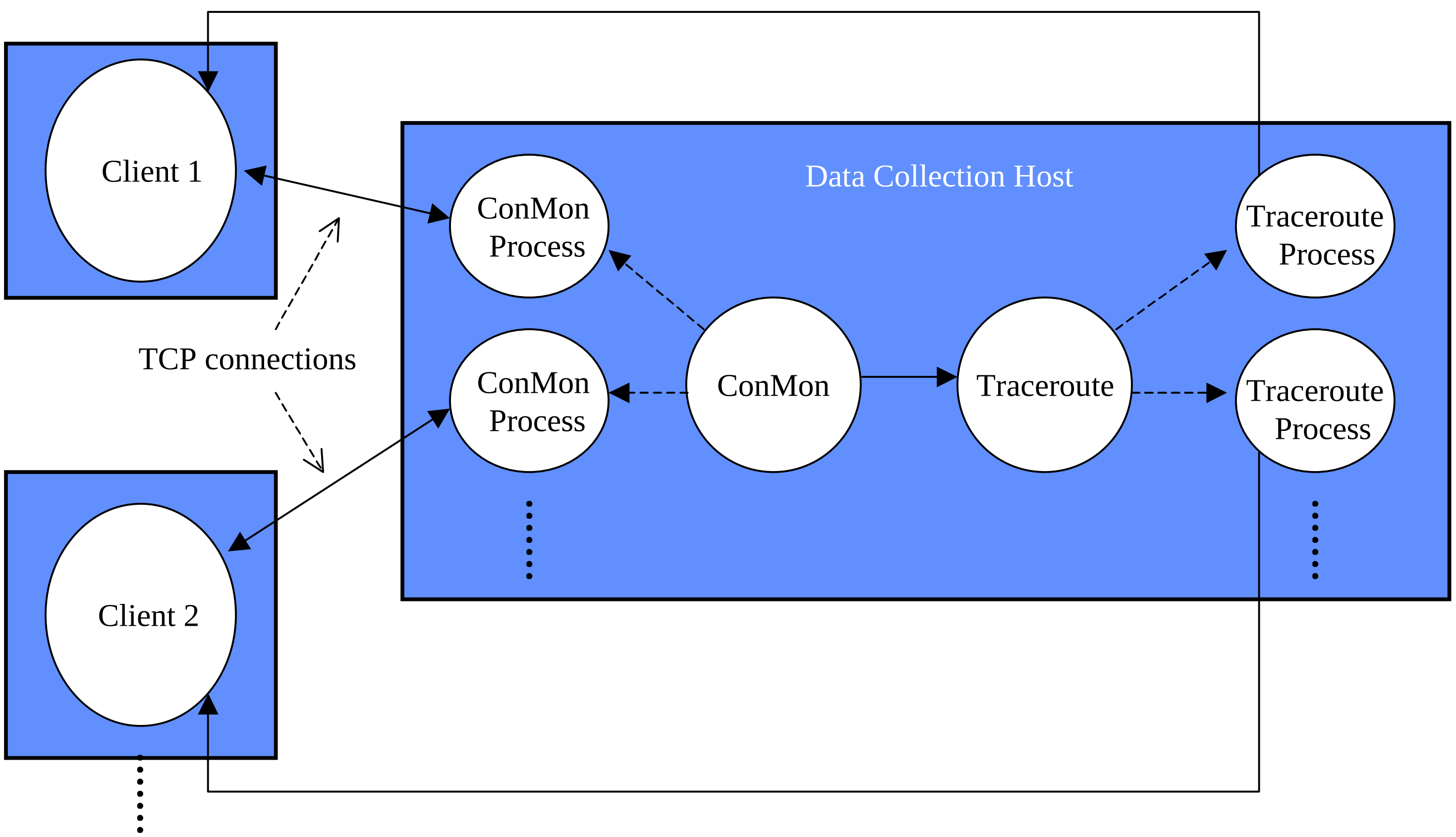
Long-term Monitoring - Motivation

- Customers want stable, fast, and low delay TCP connections
  - emerging always-on networks
  - most traffic is TCP-based
- Software developed to measure, collect, and archive measurements on TCP connections
- New tool called “ConMon”

Data Collection

- Stability
  - frequency of connection loss
  - reason for the connection loss behavior
- Throughput
  - variations and asymmetries
- Delays
  - round trip time
  - different packet sizes

ConMon - Connection Monitor



ConMon Features

- Continuous monitoring
- Measures connection stability, throughput and RTT
- Client reconnects to server when connection drops
- Excessive congestion results in a connection loss
  - from an end-user's perspective, long idle times
  - timers used to terminate a connection
- Traces the current path between the client & server
  - provides method to discern the reason for a connection loss
- Uses a plotter and table generator to display results

ConMon Operation

- Server runs on a central data collection machine
- Maintains information about parameters to use
  - packet size, frequency of transmission, number of packets/sample etc...
- Clients connect to the server
- Server notifies traceroute daemon
- Connection is monitored from both ends
- Client or server performs throughput measurement

ConMon Traceroute Facility

- Modified version of the popular *traceroute*
- Notified by ConMon daemon about client status
  - starts monitoring the path when client connects
  - stops after a timeout when a connection is lost
- Maintains a file containing number of hops, hop at which route changed and time
- File updated on observation of route change or hop unreachable

Preliminary Results

- Did not have throughput and traceroute features
- Initial results - connection very unstable
  - approximately 4-5 losses per day
  - round trip times varied widely
- Problem rectified
  - radio's were operating on an indoor channel
  - reconfigured both the SU and the AP for outdoor testing

Preliminary Results

- Connection more stable after reconfiguration
  - around 1-2 drops per day
- Simultaneous throughput tests using NetSpec
  - connection drops increased due to link saturation
  - loss rate increased as observed using mtr
- Tests also performed on cable modem network

Preliminary ConMon Measurements

- Downstream throughput

Client	Minimum (Mb/s)	Maximum (Mb/s)	Mean (Mb/s)
WLL client	0.027	9.251	6.488
Cable client 1	0.014	1.205	0.756
Cable client 2	0.023	2.019	1.380

- Customer side connection drops

Client	Connection Drops	Average Connection Hold Time (minutes)
WLL client	1219	18.93
Cable client 1	18	1648.93
Cable client 2	14	759.67
Cable client 3	21	1207.05

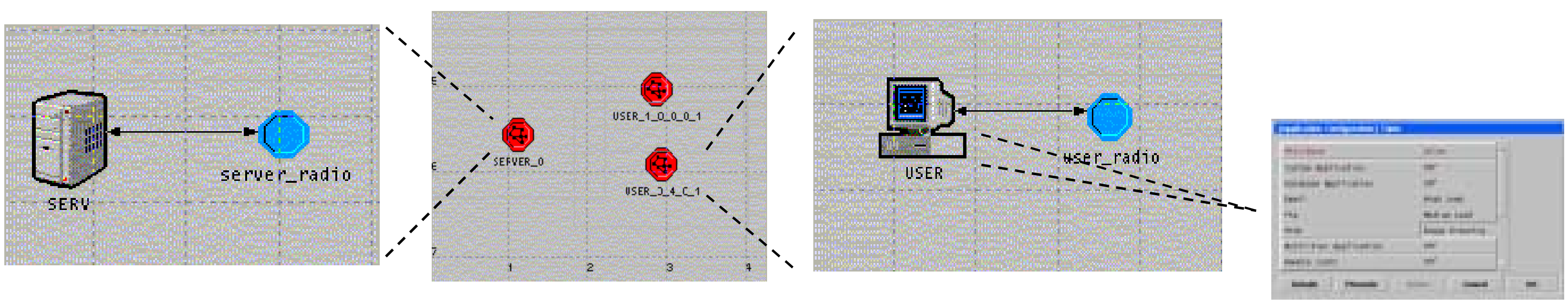
Media Access Layer Performance

MAC Layer Evaluation - Motivation

- Various MAC layer solutions offered by vendors
- Compare different approaches to MAC layer
  - media shared amongst customers
- Assess capability of MAC layers to provide particular services
  - basic best-effort Internet services
  - qualities of service or differentiated services

MAC Layer Evaluation Strategy

- Model components of typical broadband wireless MAC layers
  - contention mode and data transfer mode
- Simulate using various traffic types
  - OPNET tool used with built-in traffic models
  - particular MAC layers modeled and tested
- Tested TCP applications running end-to-end

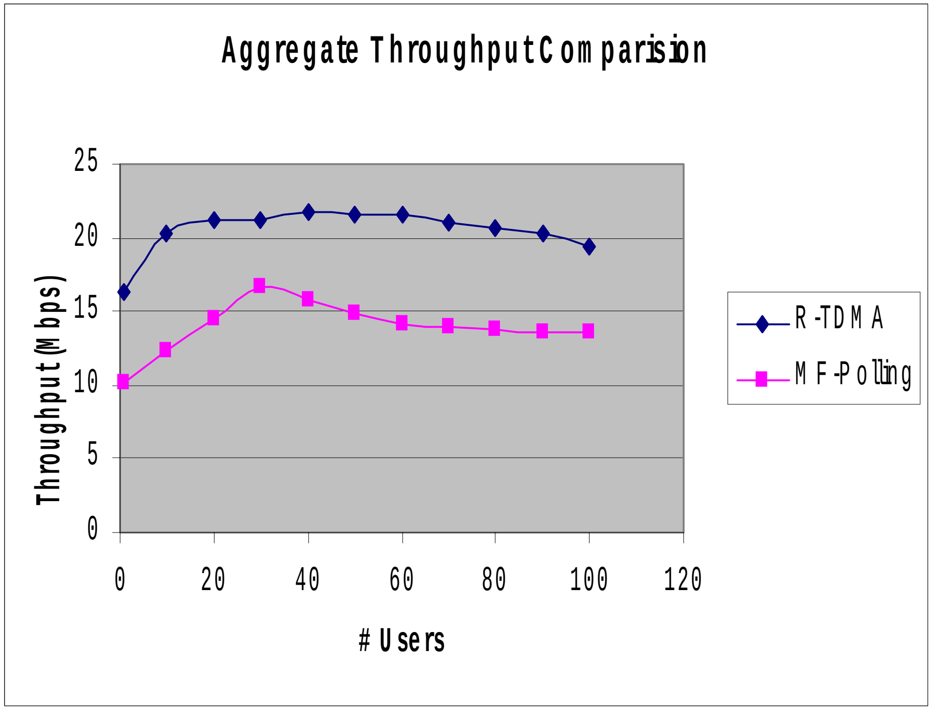


Performance Evaluation

- Test Scenarios
  - Packet Generator Test
    - To measure the performance bound of the protocols
  - FTP Tests
    - FTP Low Download
      - 1 file/hr, 10,000 bytes/file
    - FTP High Download
      - 10 files/hr, 100,000 bytes/file
  - HTTP Tests
    - HTTP Light Browsing
      - 5 pages/hr, 10 objects/page, 12000 bytes/object
    - HTTP Heavy Browsing
      - 60 pages/hr, 10 objects/page, 12000 bytes/object
  - Medium Load Test
    - FTP Low Download and HTTP Light Browsing
  - Load conditions suggested by OPNET™

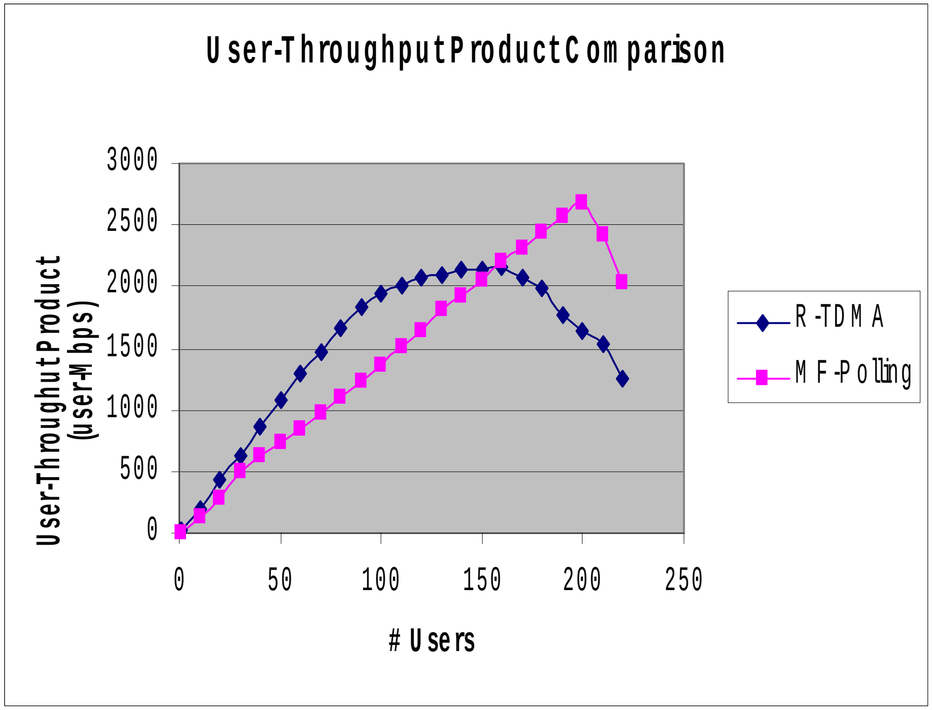
Packet Generator Test

- Shows the upper bound on the system performance
- Available bandwidth 12.5 MHz, QPSK modulation
- Tested using a packet generator with inter-arrival rate marginally greater than the link rate
- R-TDMA shows better performance than MF-Polling. However, throughput gradually decreases with increase in the number of users



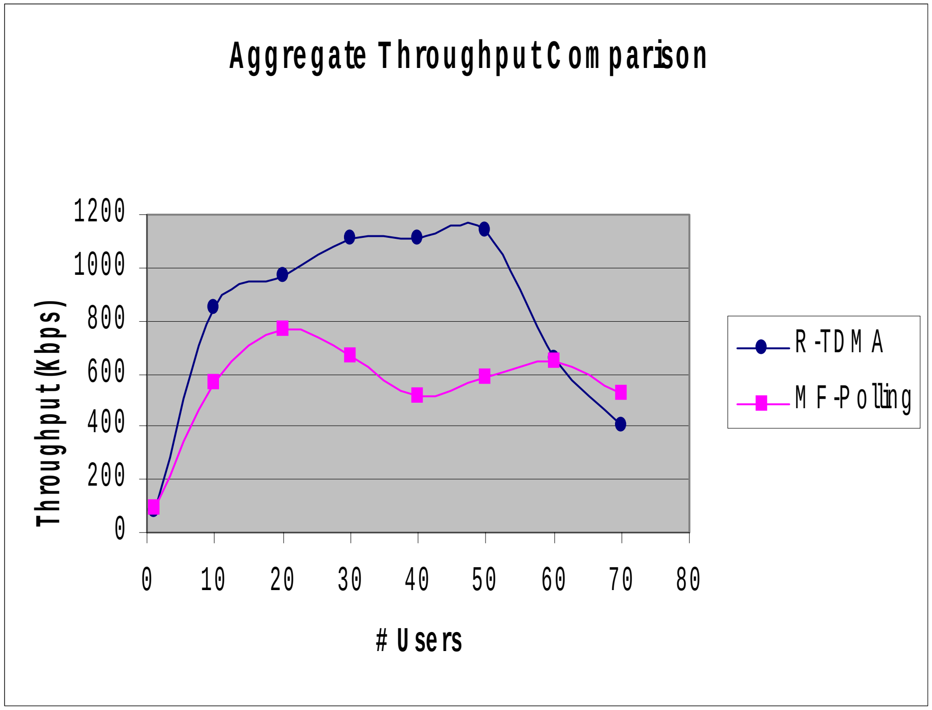
Packet Generator Test

- Devised a metric which observes the product of number of users and throughput
- The MF-Polling system supports a large user population compared to the R-TDMA system



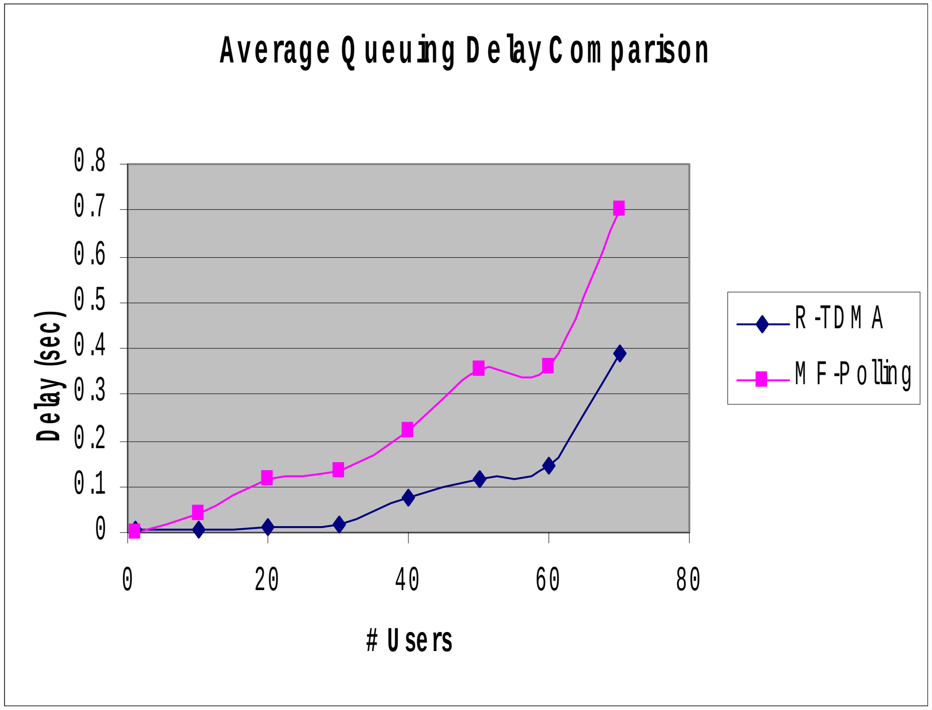
FTP Low Download

- Throughput degradation greater for R-TDMA on account of high collision
- Light load conditions lead to lower throughput for MF-Polling



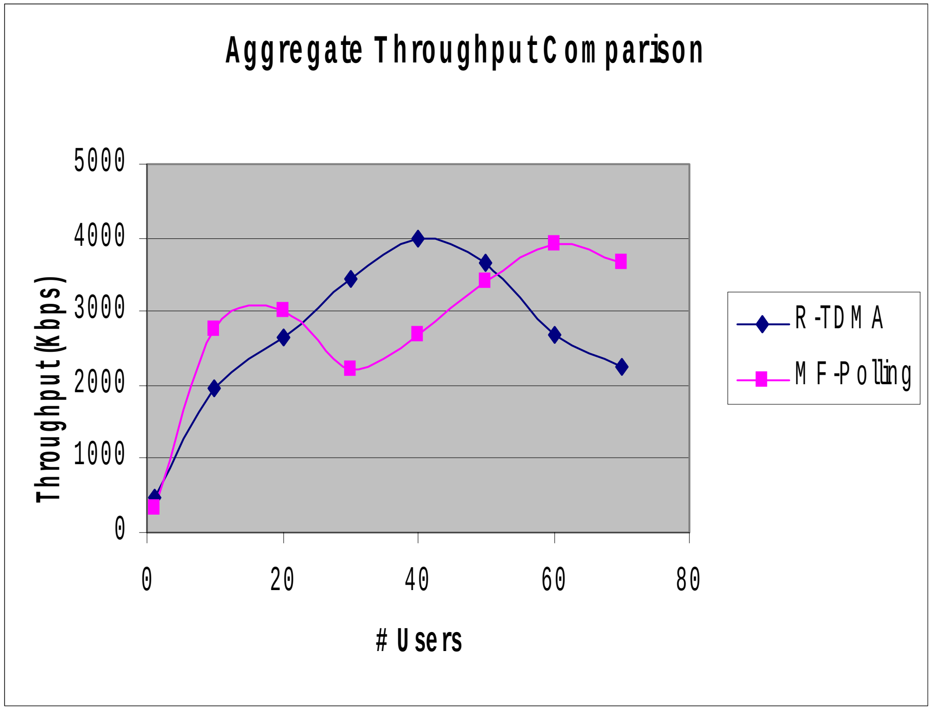
FTP Low Download

- Greater collision rate leads to steep increase in queuing delay for R-TDMA for a large user population
- Queuing delay for MF-Polling is higher than R-TDMA as data transmission is dependent on the polling cycle period



FTP High Download

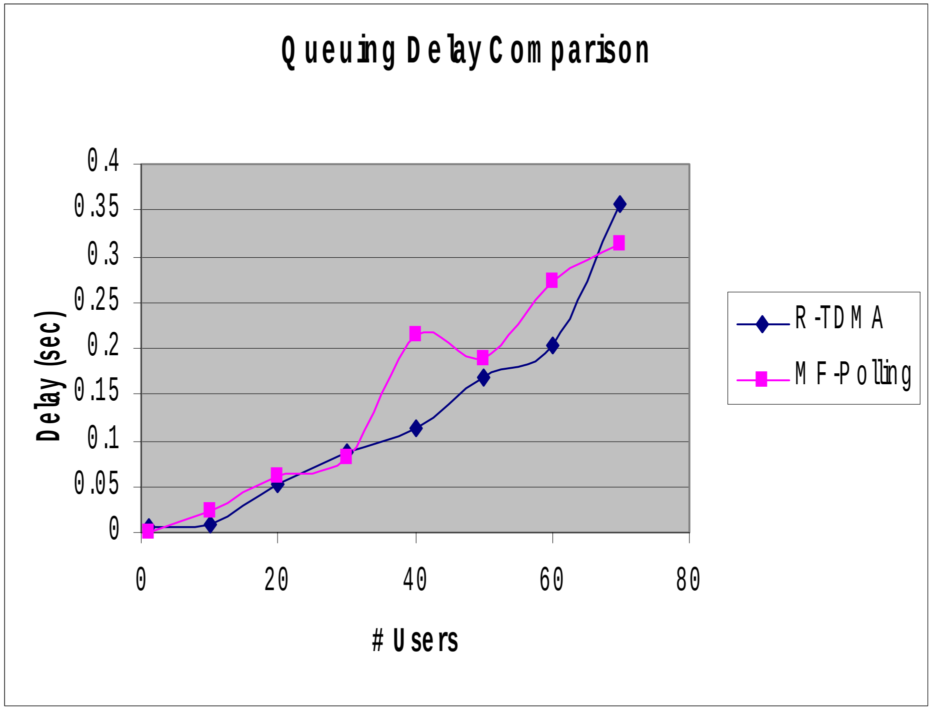
- Gradual rise in throughput for R-TDMA on account of reservation effect
- Large timeout value leads to lower contention for MF-Polling for higher number of users and thus performs better



FTP High Download

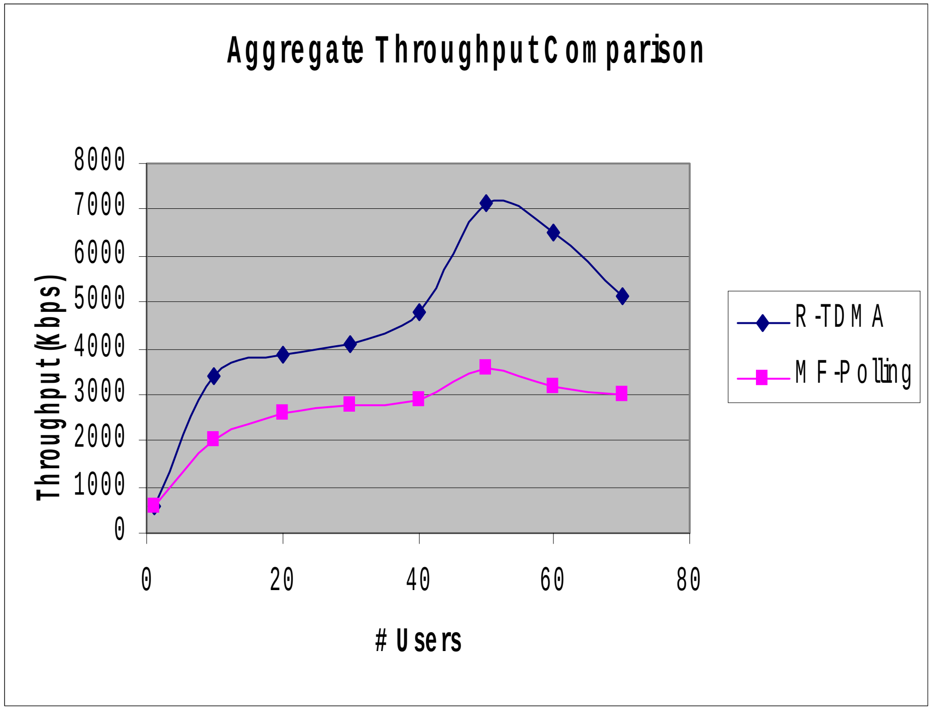
- Greater collision rate and variable number of slots leads to steep increase in queuing delay for R-TDMA for large number of users in the system

- Queuing delay for MF-Polling improves on account of reduction in contention delay and performs better as compared to the previous test case



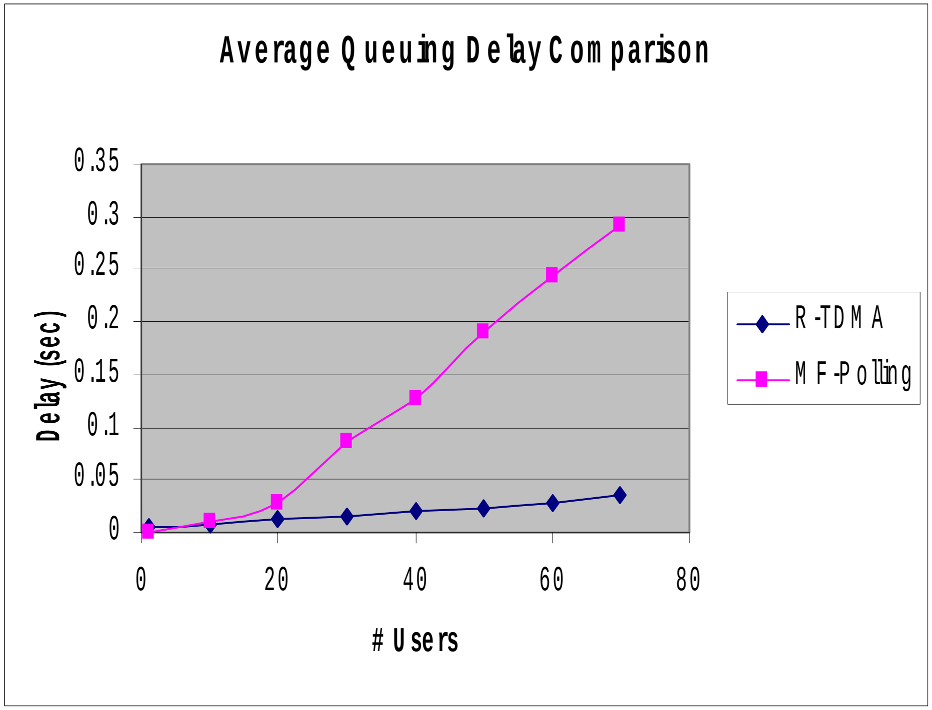
HTTP Light Browsing

- Larger amount of data, hence higher frame efficiency and continued reservation for the R-TDMA system
- MF-Polling throughput limited by the associated polling cycle time



HTTP Light Browsing

- Reservation effect leads to lower contention and lower queuing delay values for R-TDMA
- MF-Polling performance hampered on account of the large values of polling cycle time



HTTP Heavy Browsing

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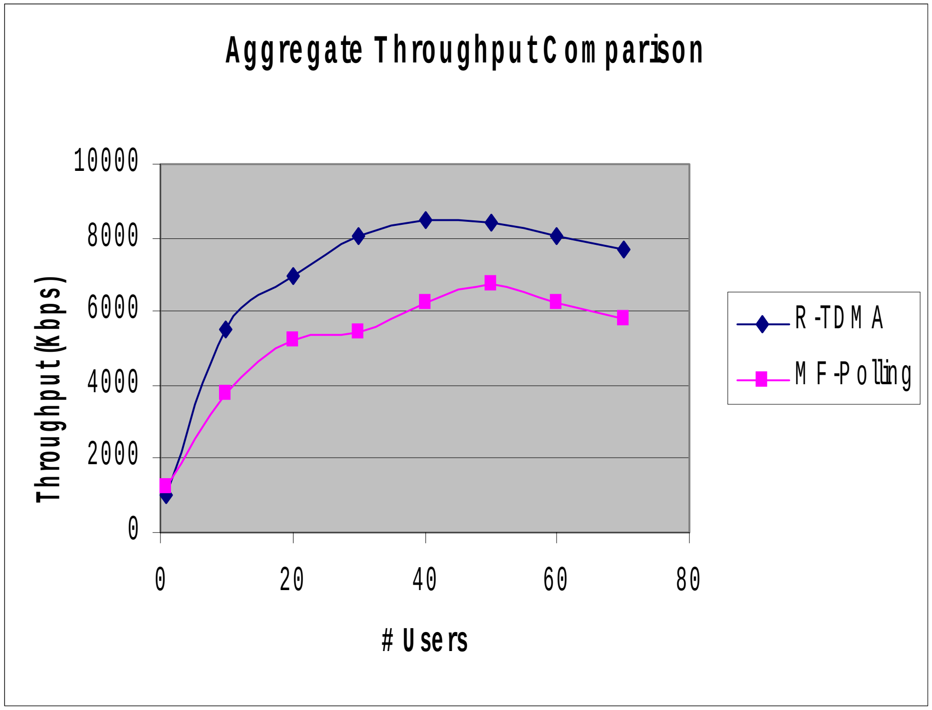
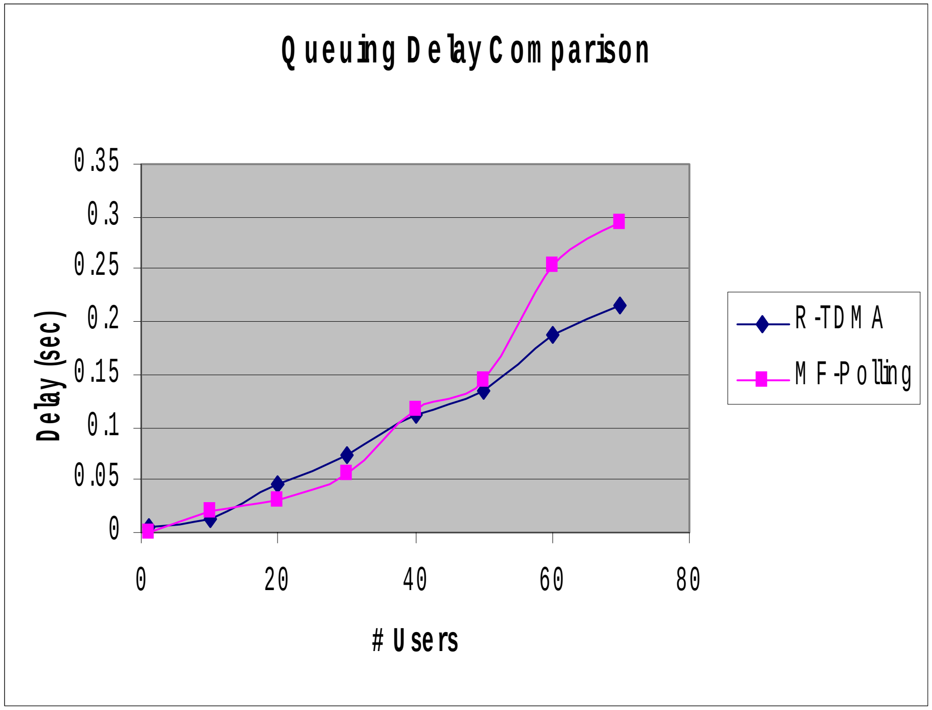


HTTP Heavy Browsing

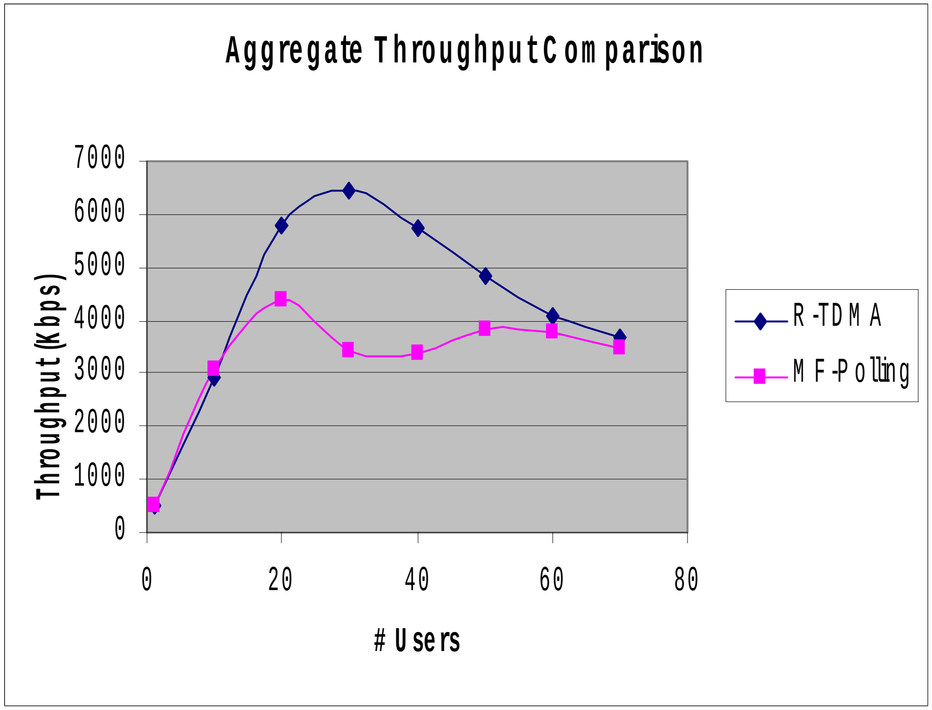
- Reservation effect in R-TDMA leads to lower contention. However, prolonged reservation leads to high queuing delay comparable to MF-Polling



Medium Load

- Combination of FTP Low Download and HTTP Light Browsing

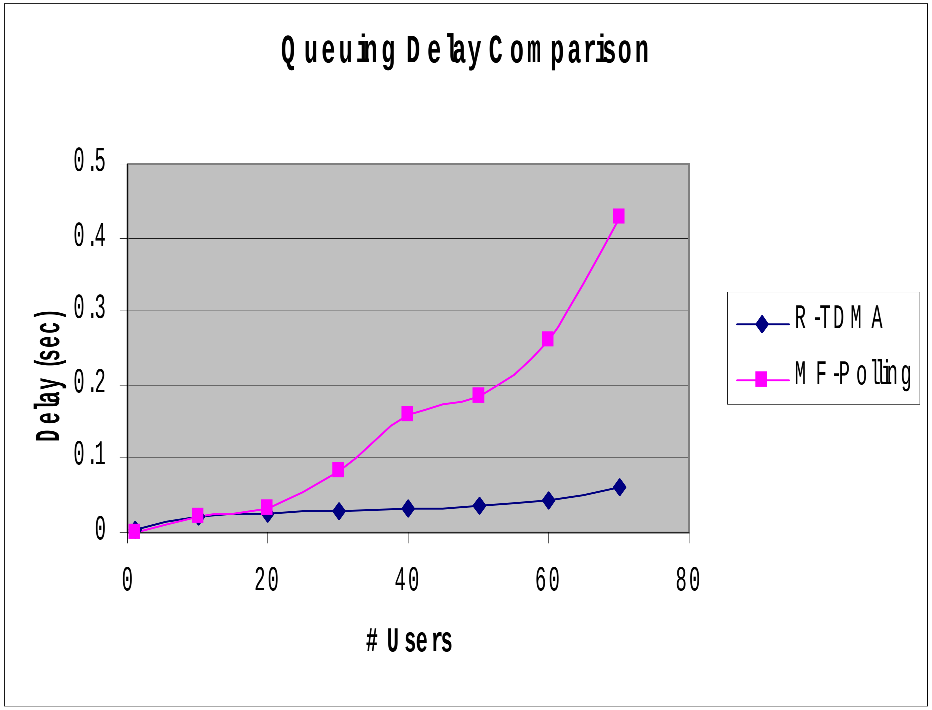
- MF-Polling throughput performance stable over a large range of users and hence can support a large user population



Medium Load

- MF-Polling queuing delay suffers on account of large contention delay and polling cycle time

- Continuous data on account of HTTP traffic aids R-TDMA to maintain reservation and thus has lower queuing delay values



Comparative Chart

Test	# Users	Aggregate Throughput	Queuing Delay	# Users Supported
Packet Generator	Low (< 50)	R-TDMA	N/A	MF-Polling
	High (>= 50)	R-TDMA	N/A	
FTP Low Download	Low	R-TDMA	R-TDMA	MF-Polling
	High	MF-Polling (R-TDMA)	R-TDMA	
FTP High Download	Low	R-TDMA	R-TDMA	MF-Polling
	High	MF-Polling	R-TDMA (MF-Polling)	
HTTP Light Browsing	Low	R-TDMA	R-TDMA	MF-Polling (R-TDMA)
	High	R-TDMA	R-TDMA	
HTTP Heavy Browsing	Low	R-TDMA	MF-Polling	R-TDMA (MF-Polling)
	High	R-TDMA (MF-Polling)	R-TDMA	
Medium Load	Low	R-TDMA	R-TDMA	MF-Polling (R-TDMA)
	High	R-TDMA	R-TDMA	

Spectrum Issues

Spectrum Issues - Motivation

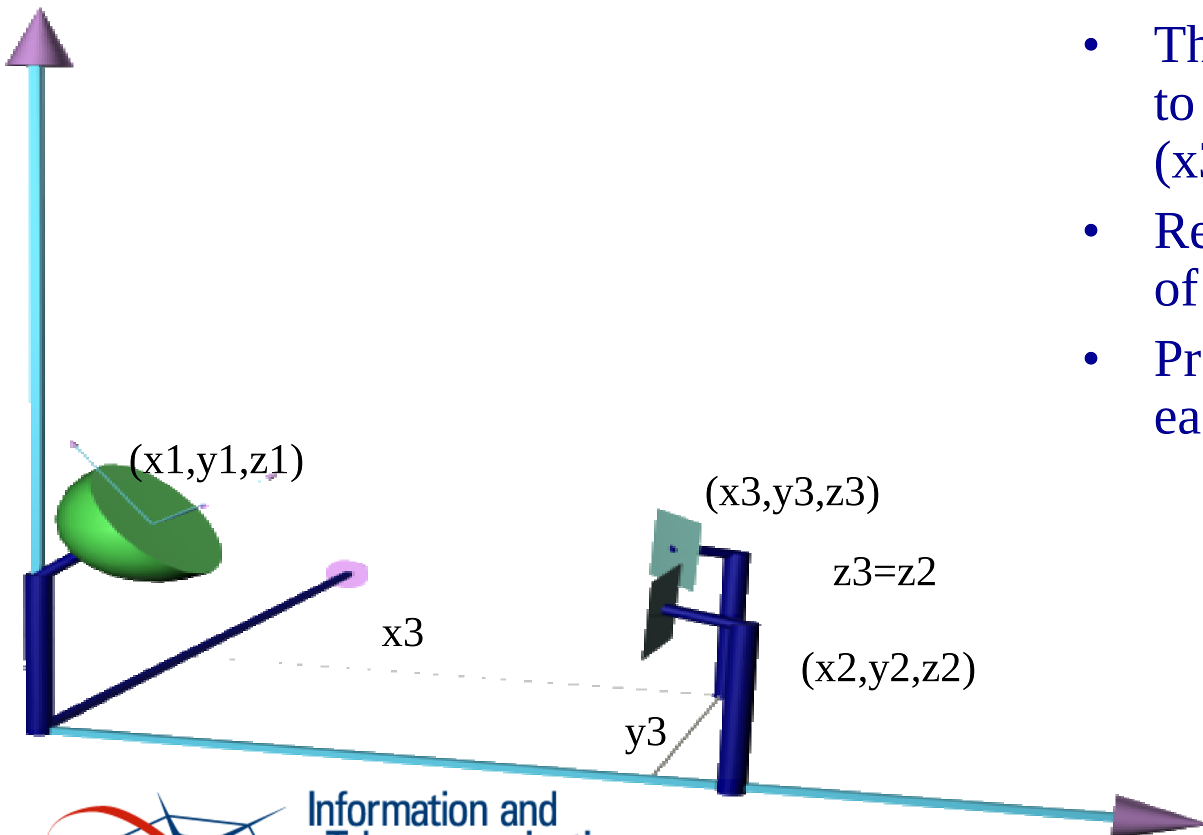
- Determine if it is possible to use a previously allocated frequency spectrum in a way that would not cause harmful interference to all other users in the area that use the same frequency
- Create a tool which will locate an adequate position for the access point in such manner that it does not cause interference, given that the data for the other antennas is provided

Interference Tool

- Receiver data required (for each receiver)
  - type of antenna (circular or rectangular aperture)
  - elevation angle
  - azimuth angle
  - x, y and z coordinate (z represents height of antenna)
- Transmitter data required
  - type of antenna
  - elevation angle
  - azimuth angle
  - radiating power
  - frequency
  - dimensions of the antenna
  - z coordinate (height only)

Interference Tool Operation

- Positions the transmitter on a certain location (x2,y2) and calculates the gains of the transmitter and the receiver in the direction of one another
- Using the two ray model, and desired interference level, calculates whether there is interference or not



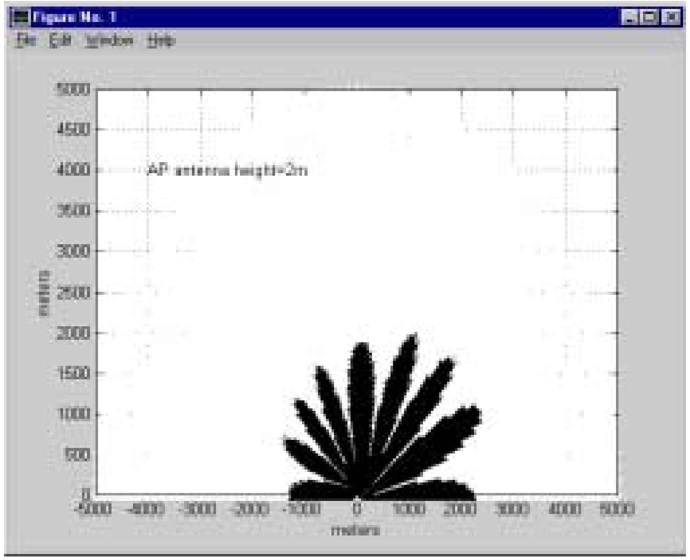
- Then moves transmitter to another location (x3,y3) and repeats
- Repeated for entire area of interest in the xy plane
- Procedure is repeated for each receiver

Simulation Example

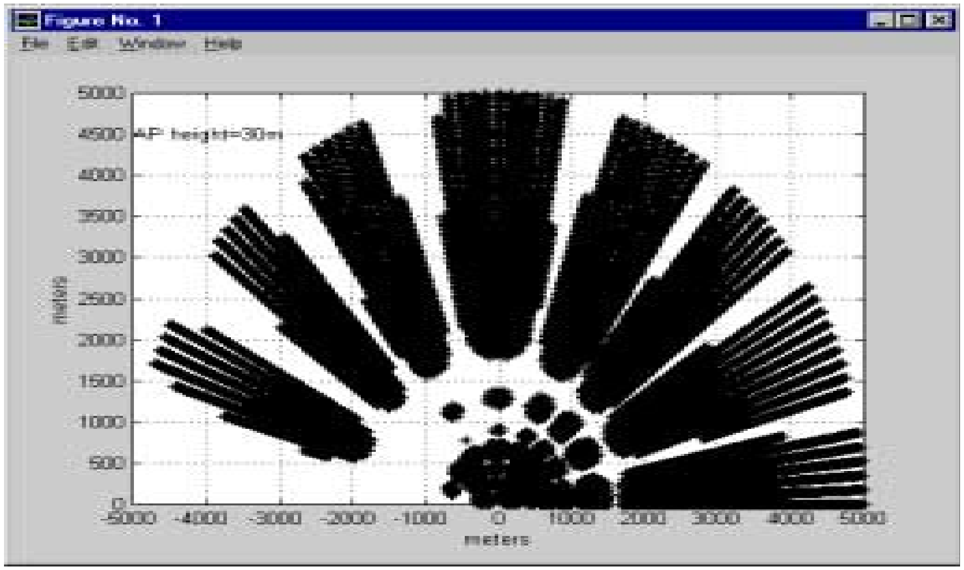
- One AP and one satellite receiver in the area
  - question - how close can the AP be placed, given that in the azimuth plane it always looks into the receiver?
  - two simulation results, for different antenna heights
- Assumptions
  - AP antenna type is rectangular aperture
  - antenna type of the other users is circular aperture
  - harmful interference level is 1 dB

Simulation Example

AP antenna height at 2 m



AP antenna height at 30 m



Conclusion

- Broadband wireless is a complex environment
  - service, link, and physical layer considerations
- Studying environment at different layers to insure that reliable and high performance services can be delivered