Improving VoIP Call Capacity over IEEE 802.11 Networks

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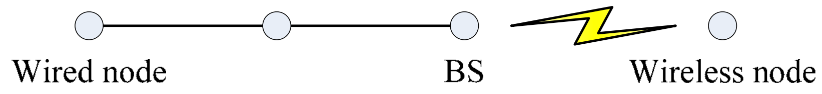
Outline

- Call Capacity Study
  - Simulations/Experimentation/Analysis
- Solution Basis
- Algorithms
- Performance Evaluation
- Conclusion

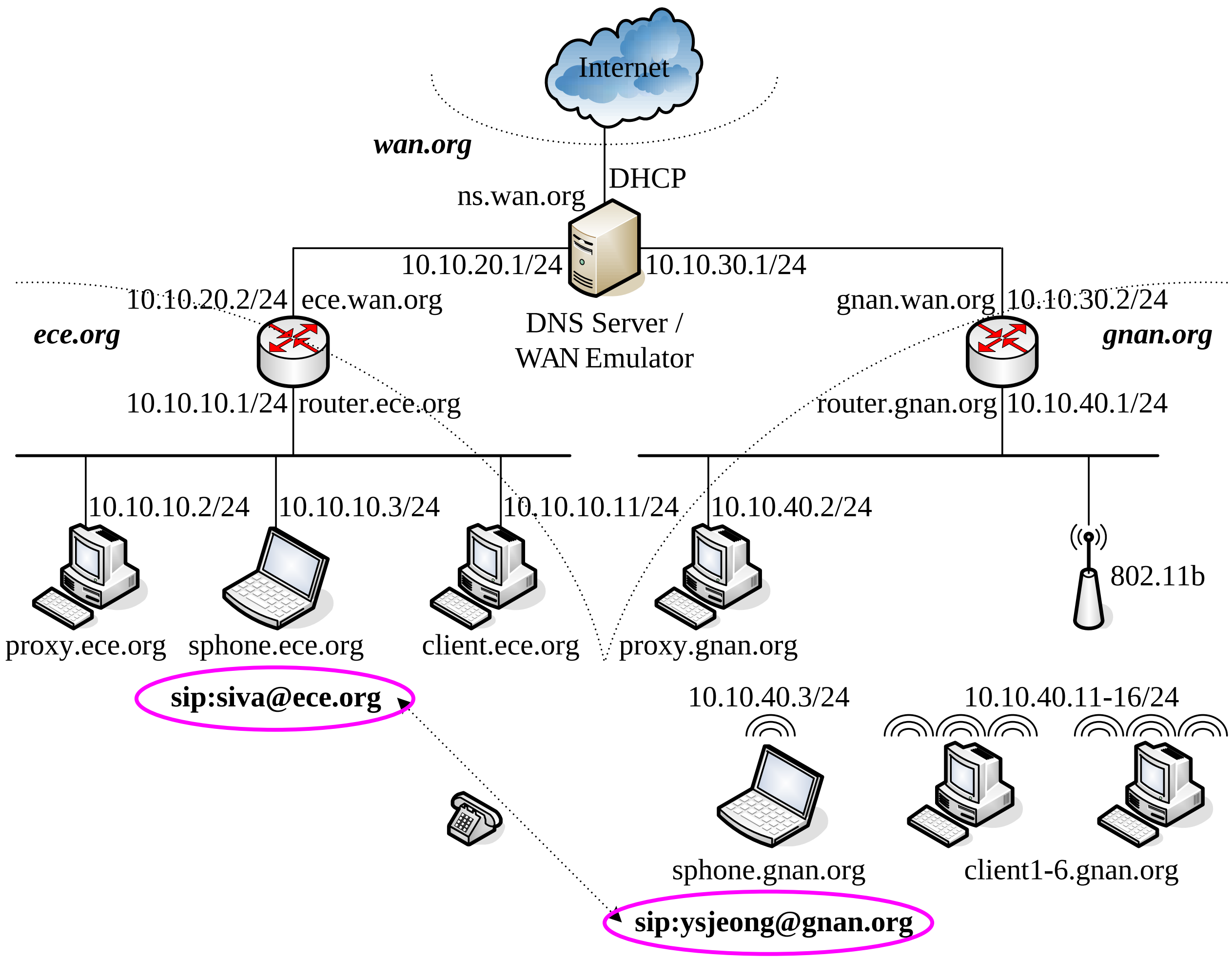
Call Capacity Study: Simulation

- Network Conditions
  - IEEE 802.11b network with 11 Mbps link
- Codec Spec of G.711
  - Frame interval: 10 ms → Frame rate: 100
  - Frame size: 80 bytes
  - Data rate: 64 Kbps
- Expected number of VoIP calls
  - **85** calls
- Actual number of VoIP calls in ns-2 simulation
  - **5** calls in ideal condition



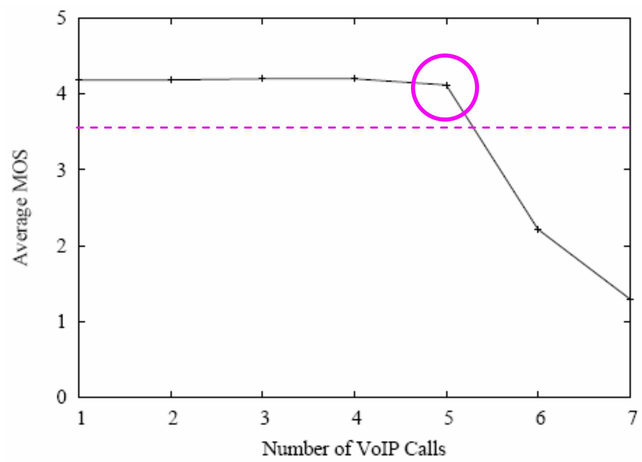
Call Capacity Study: Experimentation

- Testbed Diagram



Call Capacity Study: Experimentation

- Call Setup
  - One real VoIP call via Kphone and SIP Express Router
  - A number of emulated calls via Iperf
    - Bidirectional CBR/UDP traffic
    - Frame size: 92 bytes (considering 12 byte RTP header)
    - Data rate: 73.6 Kbps
- Actual number of VoIP calls in testbed experimentation
  - **5** calls



Call Capacity Study: Analysis

- Terminology (also used as a Metric)
  - Maximum Frame Rate (**MFR**)
    - Captures the frame rate that can be expected at each layer *L*
  - Minimum Required Transmission Delay (mRTD)
    - Gives time taken to transmit the PDU at the corresponding layer
  - Maximum Number of VoIP Calls (**MNVC**)

$$\mathrm{MNVC}(L) = \left\lfloor \frac{\mathrm{MFR}(L)}{2k} \right\rfloor = \left\lfloor \frac{1}{2k \cdot \mathrm{mRTD}(L)} \right\rfloor, \quad k \text{ is frame rate of codec}$$

Call Capacity Study: Analysis

- Application Layer Capacity
  - Ideal throughput

$$\mathrm{MFR(APP)} = \frac{R}{8D}, \quad R \text{ is transmission rate and } D \text{ is frame size}$$

$$\mathrm{MNVC(APP)} = \left\lfloor \frac{\mathrm{MFR(APP)}}{2k} \right\rfloor = \left\lfloor \frac{11 \times 10^6}{2 \times 100 \times 8 \times 80} \right\rfloor = 85$$

The potential MNVC at the application layer is **85** calls

Call Capacity Study: Analysis

- Impact of Transport and Network Layers
  - Add protocol headers to the frame

$$\mathrm{mRTD(RTP)} = \mathrm{MFR(APP)}^{-1} + \mathrm{T(RTP)}$$

$$\mathrm{mRTD(UDP)} = \mathrm{mRTD(RTP)} + \mathrm{T(UDP)}$$

$$\underline{\mathrm{mRTD(IP)} = \mathrm{mRTD(UDP)} + \mathrm{T(IP)}} \qquad \mathrm{T}(L) = \frac{8 \cdot \mathrm{H}(L)}{R}$$

$$\mathrm{mRTD(RTP)} = 58.2\mu s + 8.7\mu s = 66.9\mu s$$

$$\mathrm{mRTD(UDP)} = 66.9\mu s + 5.8\mu s = 72.7\mu s$$

$$\mathrm{mRTD(IP)} = 72.7\mu s + 14.5\mu s = 87.2\mu s$$

$$\mathrm{MNVC(IP)} = \left\lfloor \frac{1}{2k \cdot \mathrm{mRTD(IP)}} \right\rfloor = \left\lfloor \frac{1}{2 \times 100 \times 87.2 \times 10^{-6}} \right\rfloor = 57$$

The potential MNVC at the network layer, taking into account all the overheads of RTP, UDP, and IP headers, is **57** calls

Call Capacity Study: Analysis

- Impact of MAC Layer
  - Adds considerable overhead to the frame including MAC header, MAC backoff time, MAC ACK, and inter-transmission times (DIFS and SIFS)

$$\begin{aligned} \mathrm{mRTD(MAC)} &= \mathrm{mRTD(IP)} + \mathrm{T(MAC)} + T_{\mathrm{DIFS}} + T_{\mathrm{BO}} + T_{\mathrm{SIFS}} + T_{\mathrm{ACK}} \\ &= 87.2\mu s + 24.8\mu s + 50\mu s + 310\mu s + 10\mu s + 304\mu s \\ &= 786\mu s \end{aligned}$$

$$\mathrm{MNVC(MAC)} = \left\lfloor \frac{1}{2k \cdot \mathrm{mRTD(MAC)}} \right\rfloor = \left\lfloor \frac{1}{2 \times 100 \times 786 \times 10^{-6}} \right\rfloor = 6$$

The potential MNVC at the MAC layer, taking into account all the overheads of the higher layers, DIFS, SIFS, backoff delay, and ACK, is **6** calls

Call Capacity Study: Analysis

- Impact of Physical Layer
  - Adds long preamble known as PLCP header transmitted at the basic rate (1 Mbps)

$$\begin{aligned} \mathrm{mRTD(PHY)} &= \mathrm{mRTD(MAC)} + T_{\mathrm{PHY}} \\ &= 786\mu s + 192\mu s \\ &= 978\mu s \end{aligned}$$

$$\mathrm{MNVC(PHY)} = \left\lfloor \frac{1}{2k \cdot \mathrm{mRTD(PHY)}} \right\rfloor = \left\lfloor \frac{1}{2 \times 100 \times 978 \times 10^{-6}} \right\rfloor = 5$$

The potential MNVC at the PHY layer, taking into account all the overheads of the higher layers and PLCP header, is **5** calls

Solution Basis

- Final Equation for MNVC of Physical Layer

$$\mathrm{MNVC} = \frac{1}{2k\left(T_{\mathrm{DIFS}} + T_{\mathrm{BO}} + T_{\mathrm{SIFS}} + T_{\mathrm{ACK}} + T_{\mathrm{PHY}} + \dfrac{8\left(D + \sum_{L=\mathrm{RTP}}^{\mathrm{MAC}} \mathrm{H}(L)\right)}{R}\right)}$$

- Five Schemes Possible to Improve MNVC
  - ACK Aggregation (**AA**): results in the reduction of T_{ACK}
  - Frame Aggregation (**FA**): decreases k
  - Link Adaptation (**LA**): can control R
  - Time Saving (**TS**): reduces T_{DIFS}
  - Header Compression (**HC**): reduces $\Sigma\,\mathrm{H}(L)$

Solution Basis

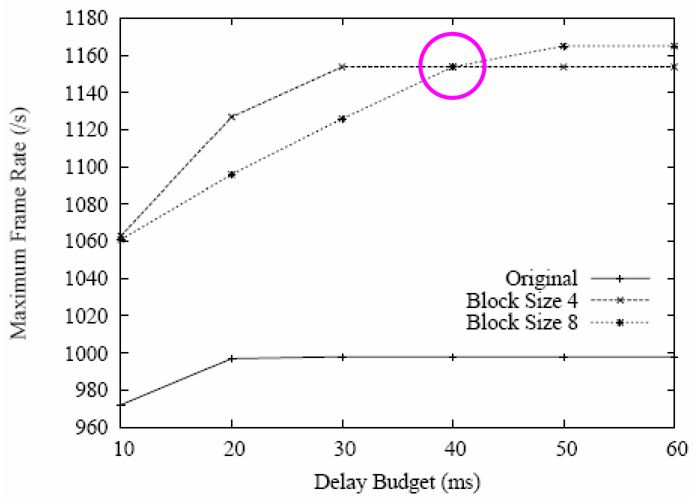
- Impact of Each Scheme on Performance Improvement

AA		FA		LA		TS		HC	
# of ACK	MNVC	k (/s)	MNVC	R (Mbps)	MNVC	T_{DIFS} (μs)	MNVC	$\sum \text{H}(L)$ (Bytes)	MNVC
1	5.1	100	5.1	11	5.1	50	5.1	74	5.1
1/2	6.1	50	9.7	5.5	4.6	10	5.3	48	5.2
1/4	6.7	25	17.4	2	3.4	0	5.4		
1/8	7.1	12.5	28.9	1	2.4				
0	7.5	6.25	43.2						

- Proposed Solutions
  - ACK Aggregation (AA)
  - Frame Aggregation (FA)
  - Link Adaptation (LA)

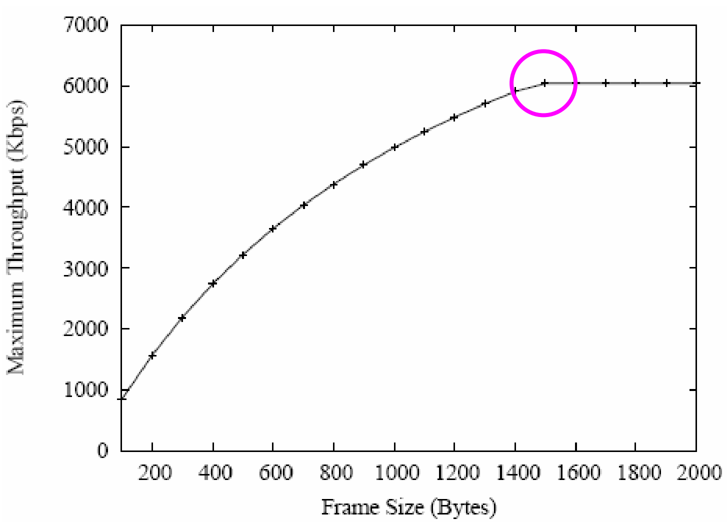
ACK Aggregation (AA)

- Motivation and Description
  - AA refers to sending a single ACK for a block of *n* frames
  - **Adaptive AA** algorithm uses variable block size based on the received block ACK information
    - Increases the block size upon receiving a block ACK with all successes
    - Decreases the block size on receiving a block ACK with even a single frame loss



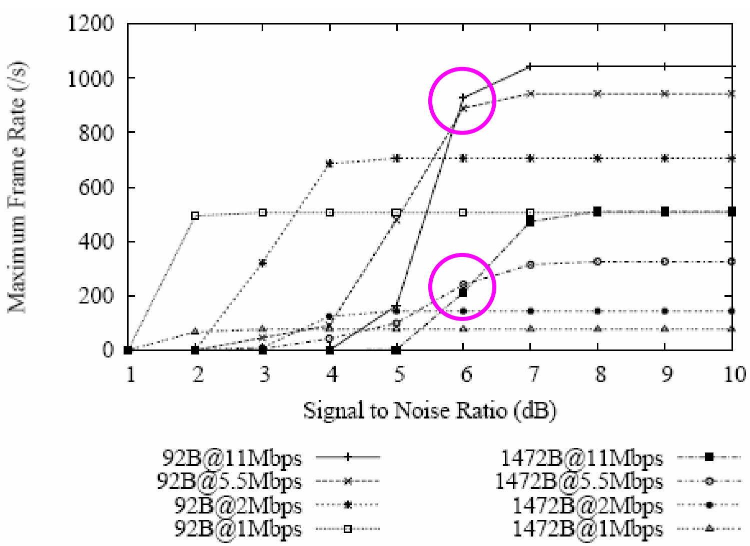
Frame Aggregation (FA)

- Motivation and Description
  - FA refers to fusing multiple frames destined to the same end user into a single large frame
  - **Enhanced piggybacking** aggregates frames only when required
    - To improve the performance of upstream flow, a client maintains a variable which holds the number of aggregated frames in the previously received frame from the AP



Link Adaptation (LA)

- Motivation and Description
  - LA refers to changing the transmission rate for the data frames
  - **SARF** (Size-aware Auto Rate Fallback) algorithm is based on ARF, but it considers channel condition as well as the frame size
    - If a small frame is in error then there is a high probability of error for a large frame as well, and when a large frame is successful, there is also a high probability of success for a small frame

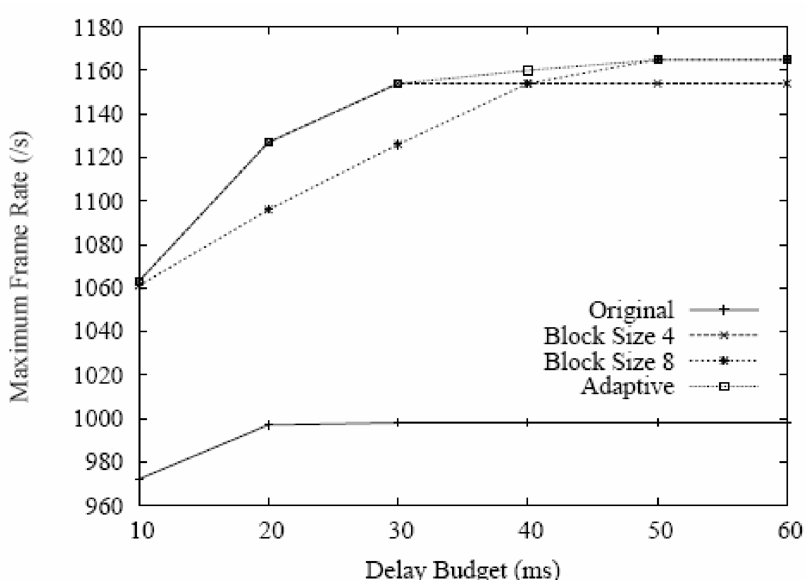


Performance Evaluation

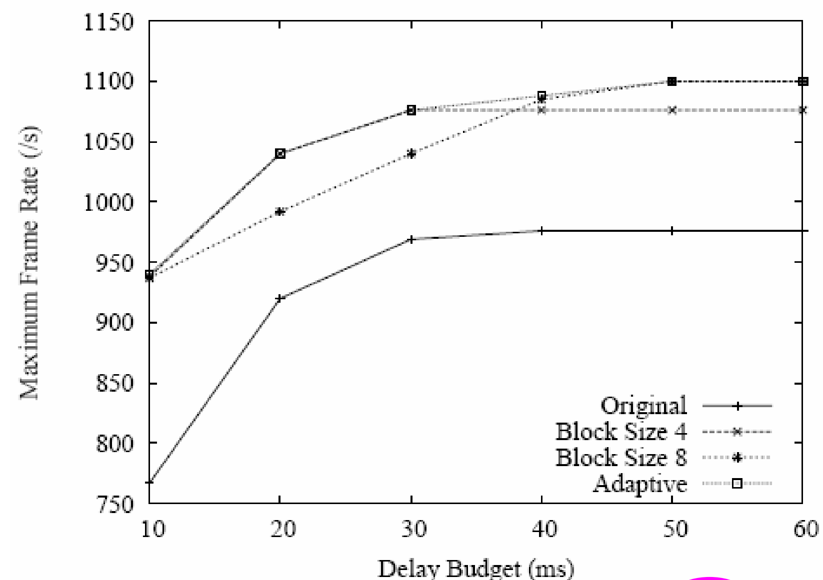
- ns-2 Simulation
  - VoIP traffic
    - Bi-directional CBR/UDP traffic with a frame size of 92 bytes
  - Background traffic
    - Bi-directional CBR/UDP traffic with a frame size of 1472 bytes
  - Number of wireless nodes
    - Single in AA and LA, multiple in FA
  - Loss rate threshold: 2 %
- Metrics
  - Maximum Frame Rate (MFR)
    - A fine grained metric for small improvement in AA and LA
  - Maximum Number of VoIP Calls (MNVC)
    - A metric for improvement of one call or more in FA

Performance Evaluation

- ACK Aggregation (AA)
  - Erroneous channels with BER of 10^{-5} and 10^{-4}



(a) MFR vs. Delay Budget with a BER of 10^{-5}

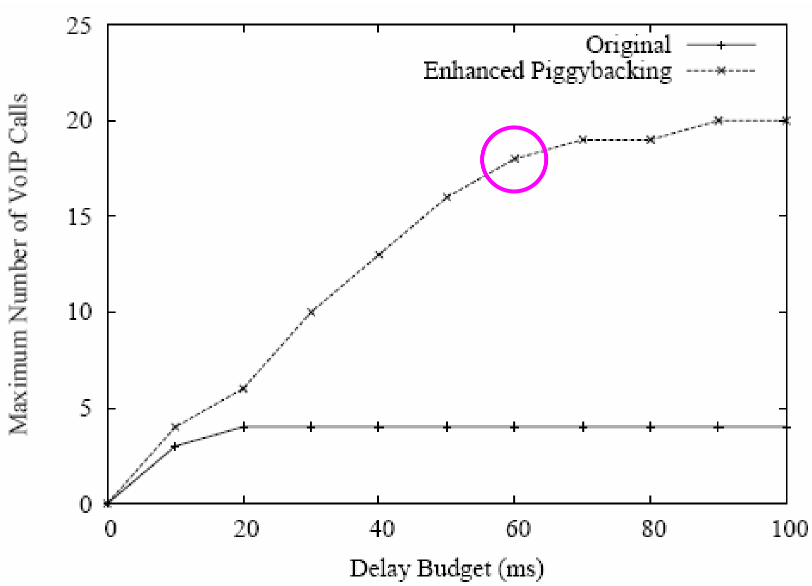


(b) MFR vs. Delay Budget with a BER of 10^{-4}

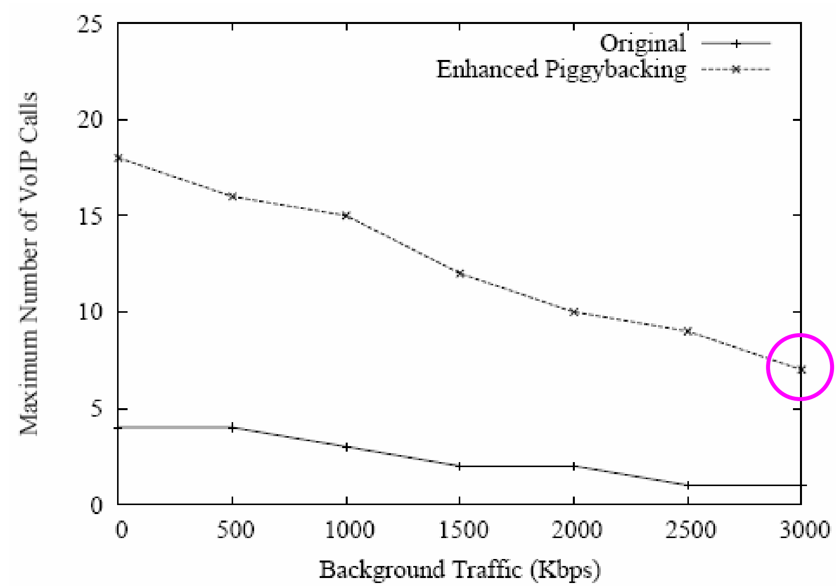
The Adaptive AA follows the envelope of two graphs with different fixed block sizes and gives the best performance

Performance Evaluation

- Frame Aggregation (FA)
  - Erroneous channel with a BER of 10^{-5}



(a) MNVC vs. Delay Budget

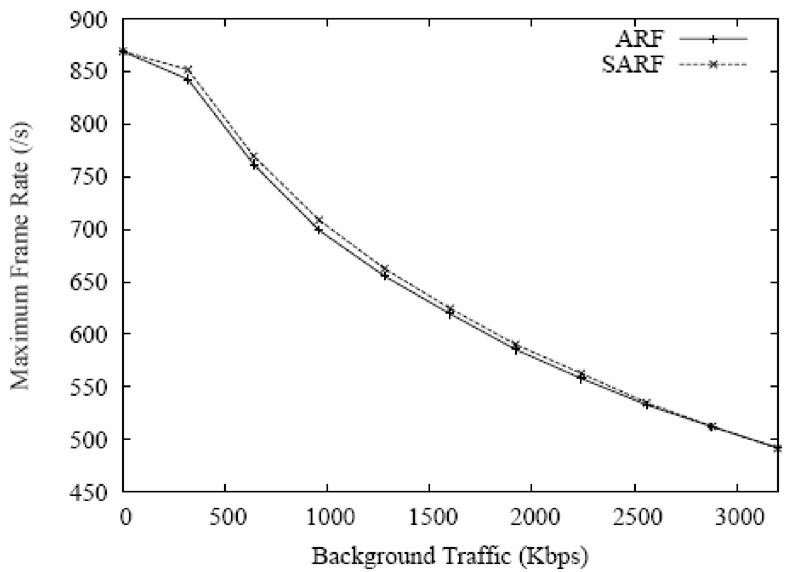


(b) MNVC vs. Background Traffi c

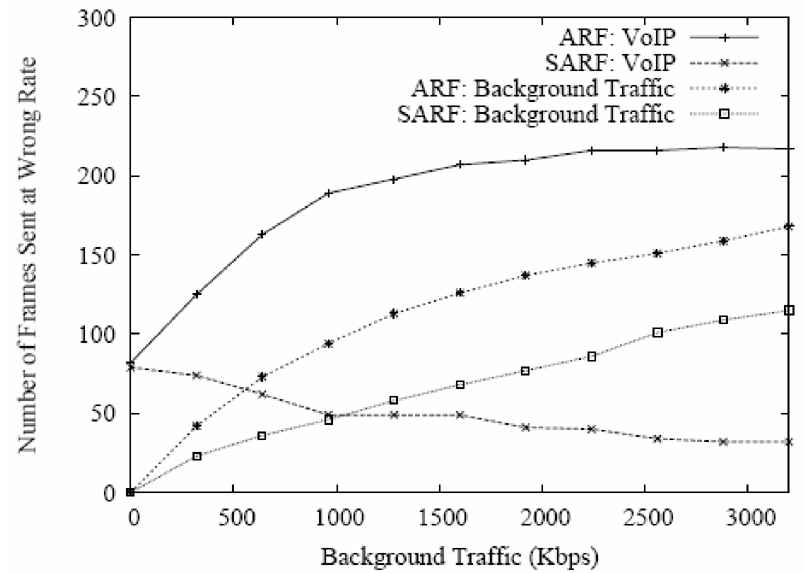
The FA gives **18** calls without any background traffic and **7** calls with a background traffic of 3 Mbps for a delay budget of 60 ms

Performance Evaluation

- Link Adaptation (LA)
  - Erroneous channel with varying SNR condition



(a) MFR vs. Background Traffi c



(b) Number of Frames Sent at Wrong Rate vs. Background Traffi c

The SARF shows similar performance to ARF in MFR but better performance in QoS metric as the number of frames sent at wrong rate

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Conclusion

- Summary
  - Analyze the reasons of the inferior performance of VoIP over IEEE 802.11 networks
  - Setup an experimental testbed to verify the analysis
  - Propose three algorithms at the MAC layer and show the performance improvement
- Ongoing Work for Software Implementation
  - Implement the FA into Linux 2.6.11 kernel in the real testbed
  - Show the performance improvement of **17** calls

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http://www.ece.gatech.edu/research/GNAN