# Adaptive QoS in 802.11e Wireless Networks for Lunar Communications


Will Spearman, Jim Martin
Clemson University, School of Computing
Clemson, SC 29632
wspearm@cs.clemson.edu, jim.martin@cs.clemson.edu


Presented by:


Jay L. Gao
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91109
Jay.L.Gao@jpl.nasa.gov

# Introduction

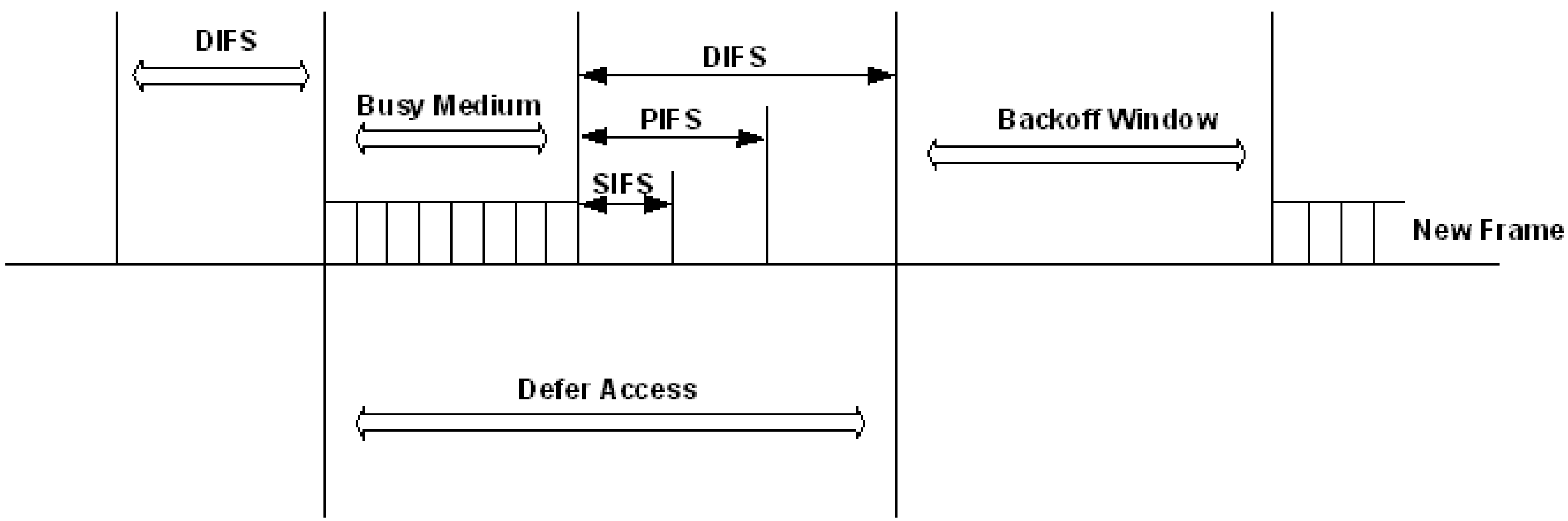
- To support future lunar surface missions:
  - Short range communication is crucial
    - Humans, sensors, vehicles, surveillance
  - Need to support voice, video, critical data, non-critical data
  - Using standardized communication infrastructure reduces cost, increases interoperability
  - 802.11 provides standardized, reliable, short-range communications
  - Data such as voice, video, and critical data need priority
- The solution – Dynamic 802.11e
  - Adds prioritization through adjustable parameters
  - Networks are dynamic
  - For each configuration and topology, there are optimal settings
  - The Adaptive Algorithm:
    - attempts to find the optimal settings as the network changes
    - requires less setup
    - administrator does not need knowledge of network characteristics
    - provides comparable performance to static 802.11e

# 802.11 MAC Layer

- Based on Carrier Sensing Multiple Access/Collision Avoidance (CSMA/CA)
- Two types of controls
  - PCF (Point Coordination Function)
    - Polling is conducted by Base Station to coordinate transmissions
  - DCF (Distributed Coordination Function)
    - Contention is resolved through random back-off scheme within a contention window. Alternatively, DCF could use Request-to-Send/Clear-to-Send (RTS/CTS) handshaking process to avoid collision.

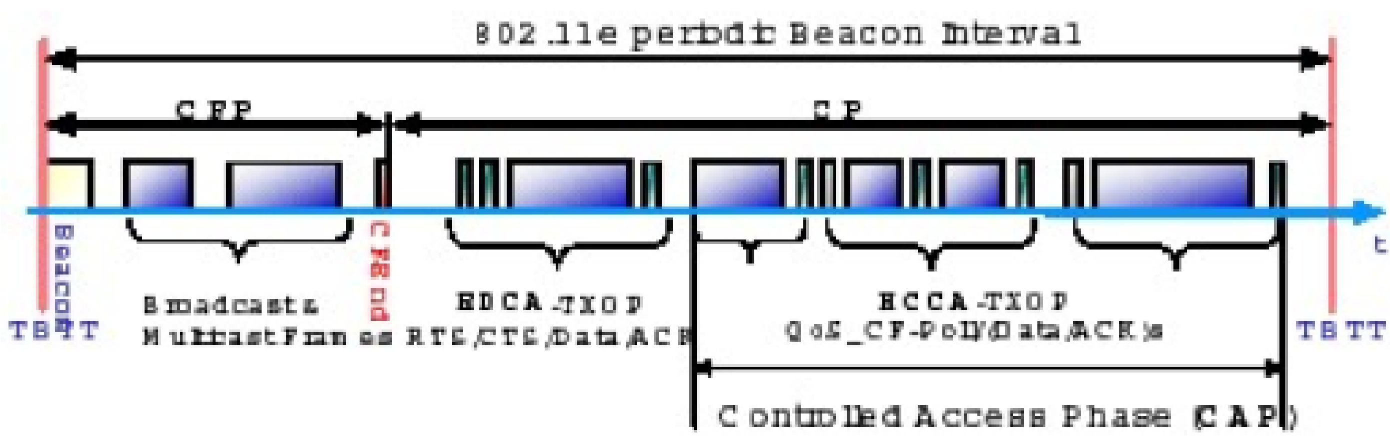
# 802.11 MAC Layer

- Access to the RF channel is controlled and prioritized by by delay parameters or Inter-frame Space (IFS)
- Each station must wait for a particular period of time or (IFS) between attempting access based on the type of message and MAC mode:
  - SIFS – shortest IFS for control and signaling such as acknowledgement or RTS/CTS messages
  - PIFS – PCF IFS is used to give priority to stations conducting contention-free access
  - DIFS – DCF IFS is used for contention-based access



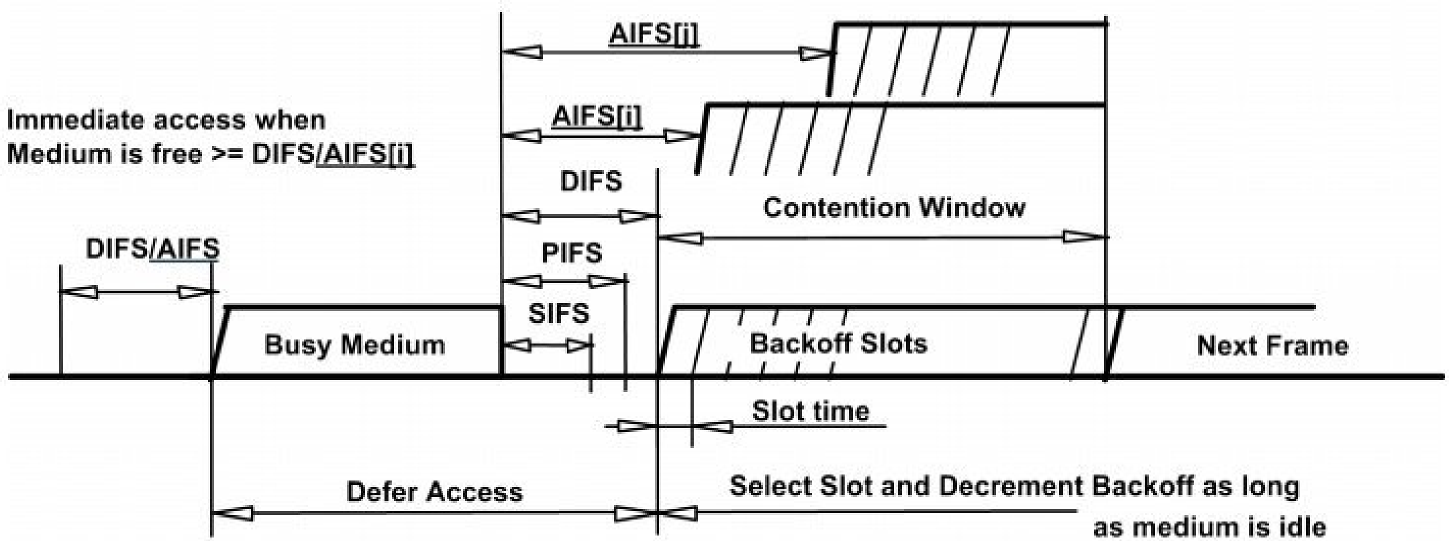
# 802.11e QoS Extension

- Hybrid Coordination Function (HCF)
  - Superframe consists of Contention Period and Contention Free Period
- HCCA – HCF Controlled Channel Access
  - Similar to PCF with configurable station ordering and parameters
- ECDA – Enhanced Distributed Channel Access
  - Similar to DCF, but uses Arbitration IFS (AIFS) to prioritize different data types



# 802.11e QoS Extension

- In this paper, we focus on the use of EDCA
- There are three parameters that controls the behavior of EDCA:
  - Arbitration IFS (AIFS) controls the access delay for different traffic class based on priority
  - In addition, CWmin and CWmax controls the range of the contention window for each data type the degree of *agressiveness* of the back-off algorithm for each traffic class



# 802.11e MAC Layer

- In general 802.11e supports four Traffic Classes (TC) with the following QoS parameter values:

| TC / Param | TC0 | TC1 | TC2 | TC3 |
|---|---|---|---|---|
| AIFS | 2 | 2 | 3 | 7 |
| CWmin | 7 | 15 | 31 | 31 |
| CWmax | 15 | 31 | 1023 | 1023 |

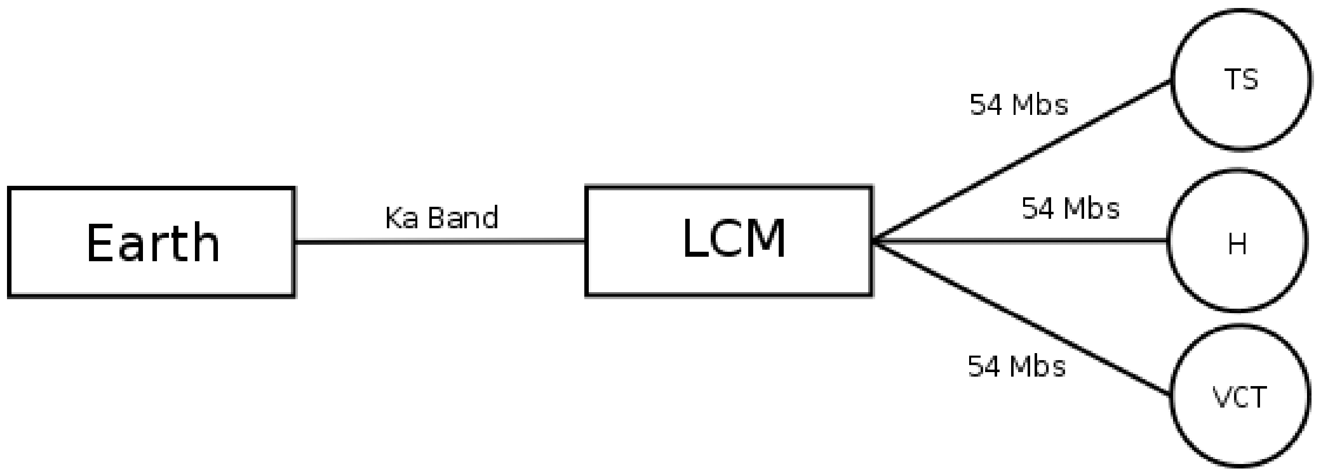
- Each TC first competes *within* a station to determine who have right to attempt access to the RF channel
  - Each queue has own parameter set: {AIFS, CWmin, CWmax}
  - AIFS is the first measure of prioritization
  - When two TC queues schedule access at the same time, it is a treated as a "virtual collision" since there is actually no transmission
  - *Virtual collisions are* resolved back-off algorithm
    - Number of back-off slots is selected randomly from [0, CW-1], CW is in the range of [CWmin, CWmax].
    - CW starts from CWmin and progressively increases with each failed attempt up to CWmax.
- TC winning the right to transmit will then compete for access to the RF channel with other 802.11 stations

# Previous Work

- Xiao, Yang; L. Haizhon; S. Choi. 2004. “Protection and Guarantee for Video and Voice Traffic in IEEE 802.11e Wireless LANs”. INFOCOM 2004. Twenty-third Annual Joint Conference of the IEEE Computer and Communication Societies. Volume 3. Issue 7-11. 2152-2162.
  - Used TxOp to prioritize stations by allocating transmit budgets
  - Contention Window adjustment based on failures and successes, not performance based
  - Window management reduces overall collisions, does not directly control priority
  - Shows that dynamic adjustment benefits the overall network compared to static priority
- Swaminathan, Arvind and James Martin. 2006. “Fairness Issues in Hybrid 802.11b/e Networks”. Consumer Communications and Networking Conference. 2006 3rd IEEE Vol. 1, Issue 8-10. 50-54.
  - Examined 802.11e parameters and individual impact on performance
  - Found AIFS was most aggressive, CWmax next, CWmin was least aggressive
- Cali, F; M. Conti; E. Gregori. 2000, “Dynamic Tuning of the IEEE 802.11 Protocol to Achieve a Theoretical Throughput Limit”. IEEE/ACM Transactions On Networking, Vol. 8, No. 6, December 2000, 785-799
  - Adjusted Contention Window based on number of active stations
  - Found that various network conditions require different parameter settings to achieve optimal performance
  - Found that static parameters lead to under-utilization of bandwidth

# A Simple Network Topology

- Lunar Surface Network based on 802.11e
- Multiple surface elements are connected to a Lunar Communications Module (LCM) via the 802.11e protocol. The LCM relays data to Earth via high capacity, point-to-point Ka-band link.
- Each surface element can transmit the following data types:
  - V → Voice communications
  - C → Command and Control Data
  - T → Telemetry (includes operations and engineering data)
  - S → SD video (situational awareness and monitoring)
  - H → HD Video (public engagement and documentation)



# Using 802.11e TC for Lunar Communication Scenarios

- Map NASA data types to the four traffic classes
- Assume the following priority order voice, command, telemetry, SD video and HD video based on *operation/safety considerations, not bandwidth consumption*.
  - Even though video has higher jitter delay problem, it is assigned to lower priority as it is not mission critical.
- *Key Question: Would an adaptive algorithm for automatic tuning of QoS parameters provide performance gain over the off-the-shelf 802.11e default configuration?*

# Simulation Study of Applying Adaptive vs. Static 802.11e QoS

- Three cases are studies:
  - Case 1: No QoS, all traffic set to same TC
  - Case 2: 802.11e with static QoS
  - Case 3: 802.11e with automatic tuning of QoS
- Assigned voice to TC0, command to TC1, Telemetry to TC2, Video (both SD/HD) to TC3
- We take an previously proposed adaptive QoS algorithm developed for 802.11e and apply it for lunar communication scenarios
  - W. Spearman, J. Martin, “A distributed Adaptive Algorithm for QoS in 802.11e Wireless Networks”, SPECTS’07, San Diego, California, July 2007.

| Type / Attribute | Voice | Command | Telemetry | SD Video | HD Video |
|---|---|---|---|---|---|
| Protocol | UDP | TCP | UDP | UDP | UDP |
| Profile | CBR | CBR | CBR | VBR | VBR |
| Rate (kbps) | 8 | 13 | 248 | 4000 | 12000 |
| Packet (bytes) | 20 | 1000 | 1000 | 2048 | 2048 |
| AR_PRESET | 1.5 | 5.0 | 15 | 35 | 35 |
| Normal Priority | TC0 | TC1 | TC2 | TC3 | TC3 |
| Metrics | Throughput, Jitter | Round Trip Time | Throughput, Jitter | Throughput, Jitter | Throughput, Jitter |

- ns2 version 2.28 with EDCA extension

# Description of Adaptive QoS Algorithm

- Adaptive Algorithm will tune AIFS, CWmin, CWmax based on delay performance:
  - Periodically lowers QoS parameters to probe the shortest achievable delay for the highest priority TC
  - Use the measured delay as a optimal "goal"
  - For each TC, Aggressive Ratio (ar) measures the difference between the current delay and the optimal goal
  - Network administrator control the aggressive ratio for each TC by an AR_PRESET value – i.e., how close the performance should be relative to the optimal
  - ar_diff = ar/AR_PRESET shows a node's relative performance according to the network management's setting

# Description of Adaptive QoS Algorithm

- Adjustment of parameters – Increase or decrease
  - ar_diff is less than 1 → performing too aggressively
  - ar_diff approx equal to 1 → performing well
  - ar_diff greater than 1 → performing too passively
- Adjustment of parameters – aggressive or relaxed
  - Relaxed Change if ar_diff is close to 1
  - Aggressive Change if ar_diff is far from 1

| ar_diff | very low | low | good | high | very high |
|---|---|---|---|---|---|
| Change | a- | r- | none | r+ | a+ |

← decrease value          increase value →

# Description of Adaptive QoS Algorithm

- Prior research results have shown that AIFS provides the best level of service for high priority traffic since in all cases it provides the lowest access times. Prioritization based on CWmax provides the next best service and prioritization based on CWmin provides the least aggressive service.

- Therefore to implement aggressive adjust one starts with AIFS, to implement “relaxed change” one starts with CWmin.

- Parameter Adjustments
  - Relaxed change
    - If not at min/max bound, adjust CWmin
    - Else If not at min/max bound, adjust CWmax
    - Else If not at min/max, adjust AIFS
    - Else, do nothing
  - Aggressive change
    - Reversed the order of parameter adjustment

# Simulation Setup

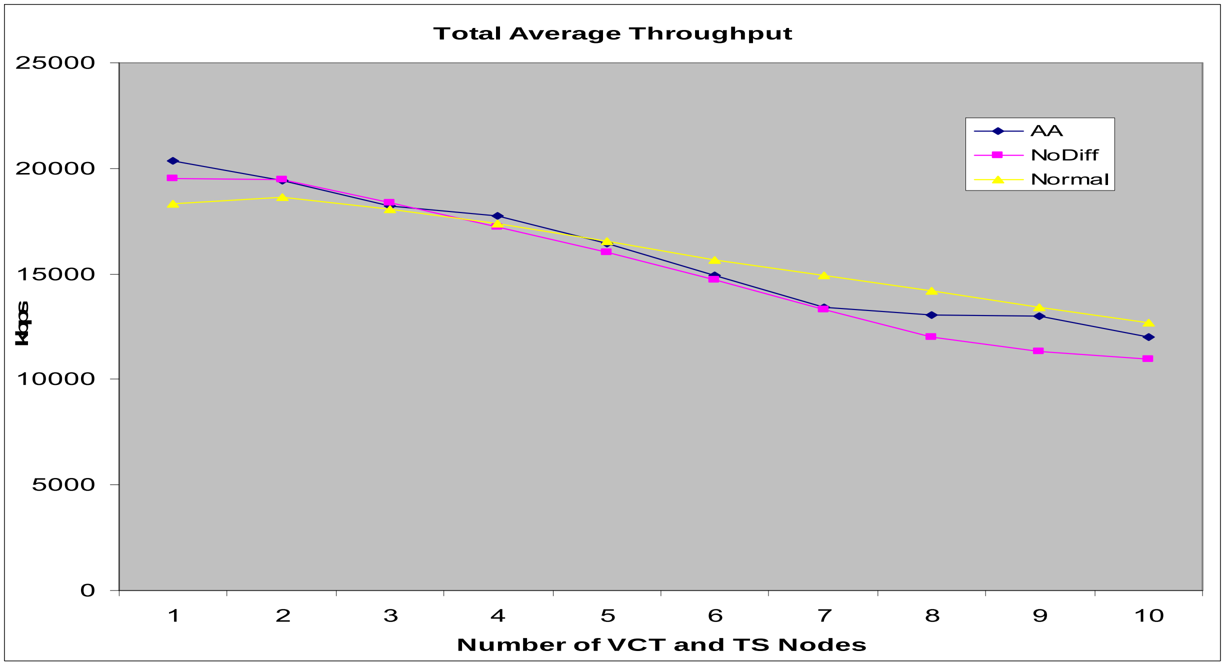
- Throughput and delay jitters were measured for the proposed 802.11e topology
  - Number of VCT and TS stations varies for each data point
  - Number of H nodes are fixed at two for all simulation runs
  - For example, data point #5 has 12 stations
    - 5 stations with V,C,T
    - 5 stations with T,SD Video
    - 2 stations with HD Video

- Voice, Command, and Telemetry flows are modeled by Constant Bit Rate sources
- Videos are modeled by Variable Bit Rate sources

- Three simulation types
  - **NoDiff**: all data flows and stations use TC2 parameters (no QoS)
  - **Normal**: each TC use default configuration of 802.11e
  - **AA**: each TC start with TC3 values, use AA to adjust QoS configuration

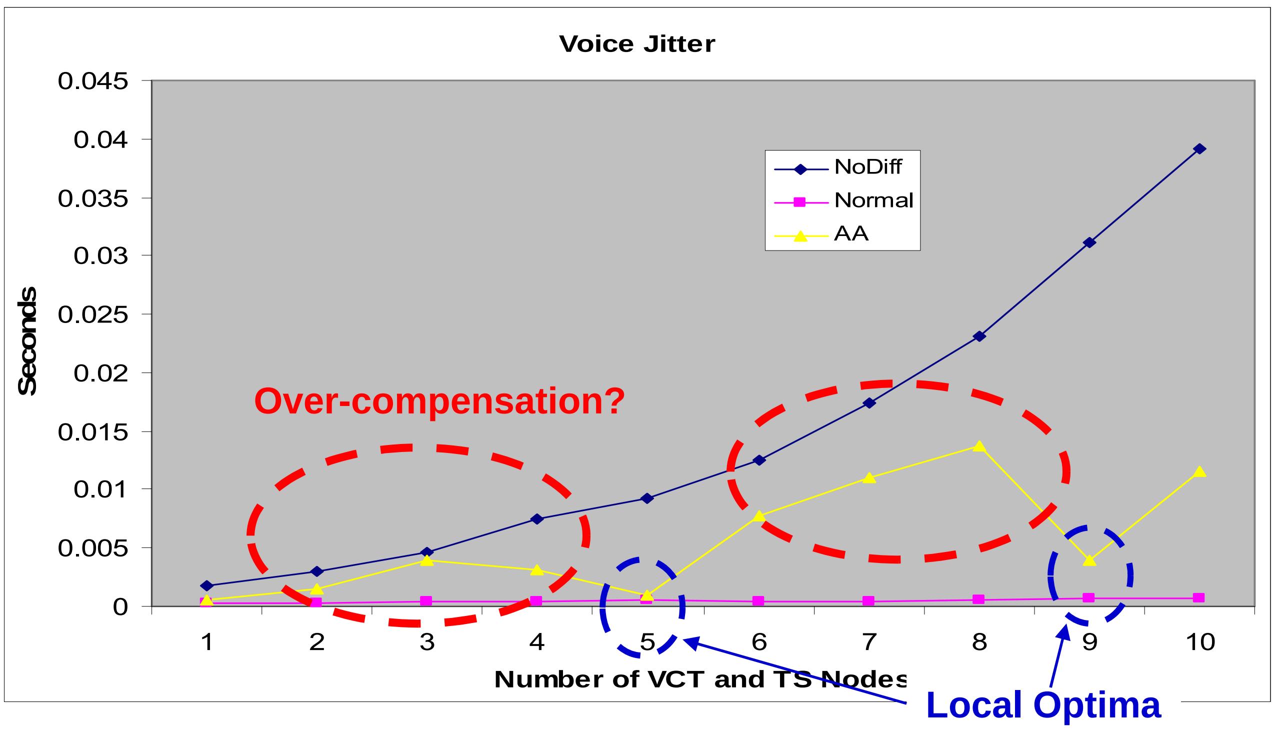
# Results: Throughput

- No significant Throughput differences were observed
- Network utilization remains high even with the additional QoS arbitration process and AA algorithm
- QoS mechanism manipulates transmission ordering without introducing overhead in the access contention process



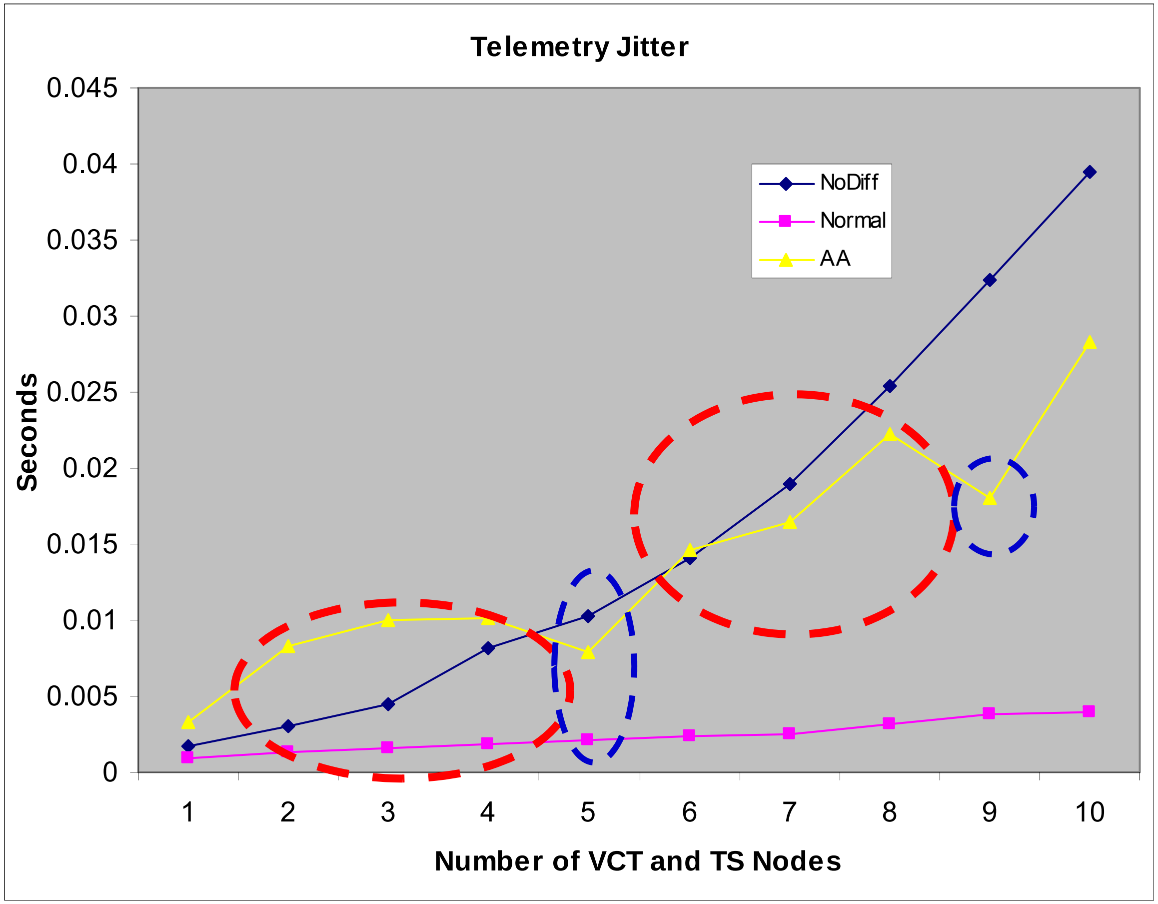
# Results: Voice Jitter

- AA Out performs NoDiff but not as good as Normal configuration.
- Voice traffic is CBR and therefore given the lowest AIFS, it receives highest priority over other traffic and there will be no queue-built. Therefore, adaptive scheme, which is designed for arbitration of resource under congestion does not play a significant role.
- In general AA should not operate on voice. Higher jitter could be the result of over-compensation in the algorithm to maintain AR_PRESET level.
- AA jitter curve shows "humps" of degraded performance with local optima near data point #5 and again #9. There seems to be a "resonance" frequency in the algorithm.



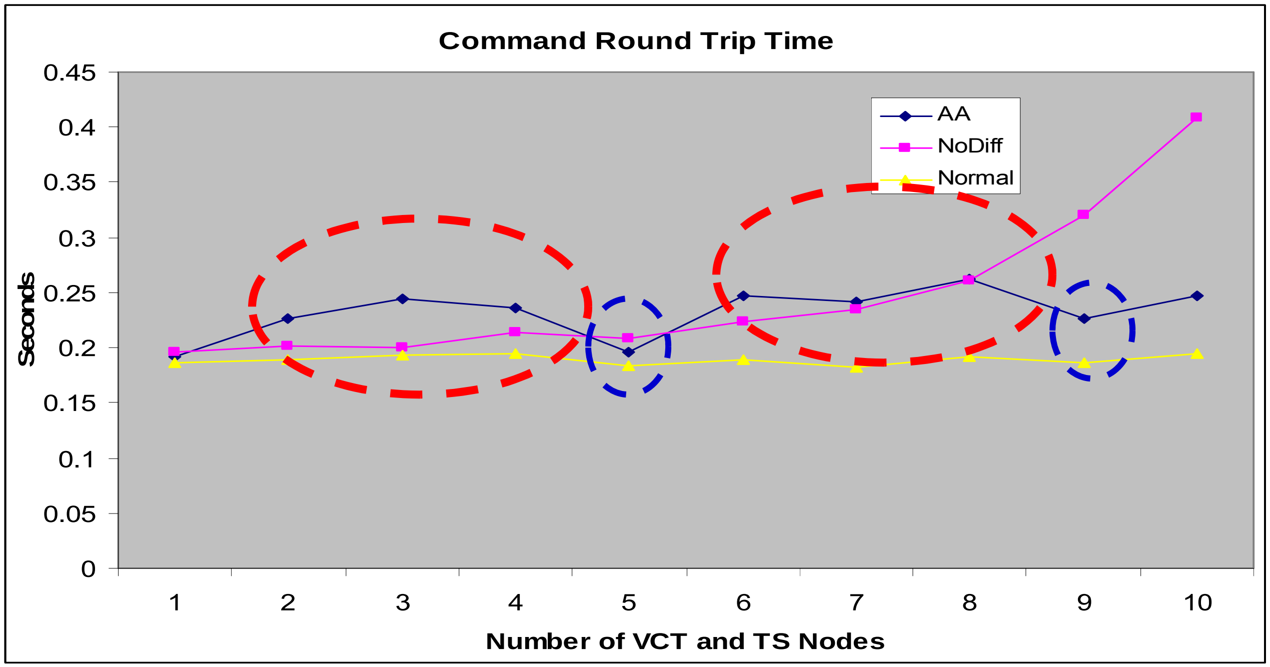
# Results: Telemetry Jitter

- Similar to Voice, AA curve shows "humps" that indicate over-compensation and sensitivity to network size.



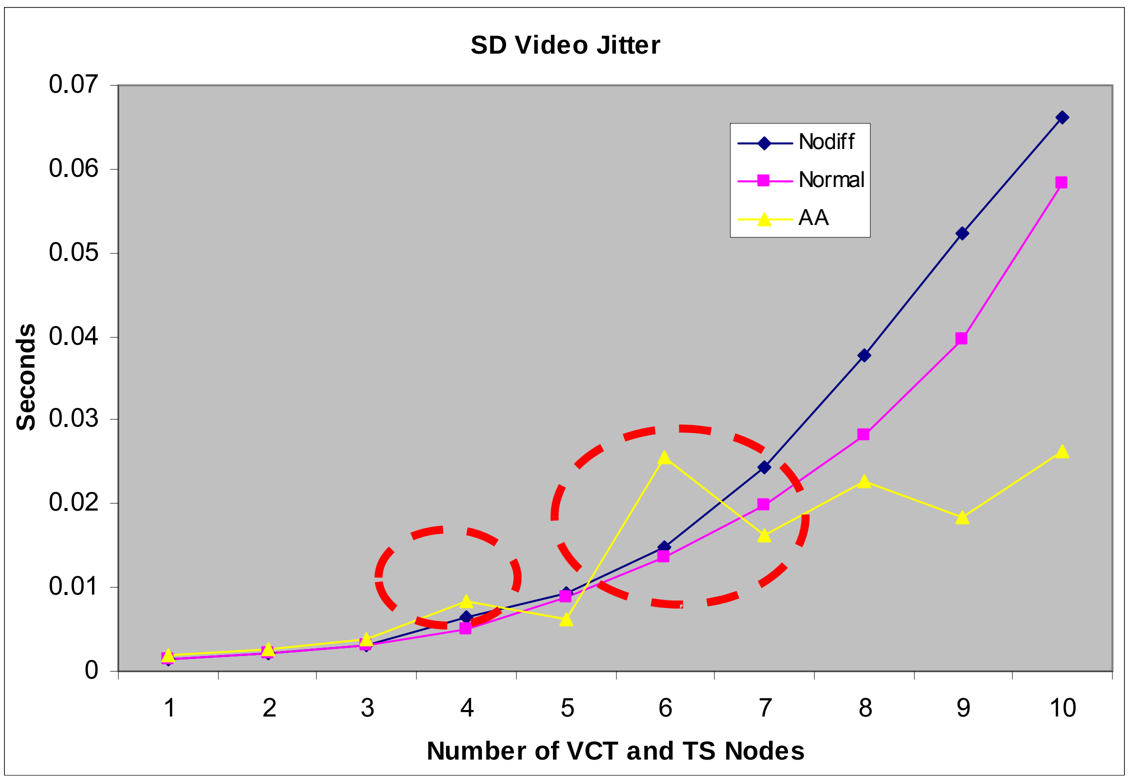
# Results: Command

- AA has higher RTTs but does not suffer increases as the network becomes heavily overloaded as does NoDiff. AA experiences more variability than both others.



# Results: SD Video Jitter

- AA provides lowest jitter for video sources as network size increases.
- Again performance does not provide consistent trend and indicates resonance in the control algorithm to the number of network elements.
- Video is VBR and therefore subject to congestion-driven jitter. AA algorithm provides significant mitigation to jitter compare to NoDiff and Normal configuration.



# Summary of Findings

- 802.11e QoS enables prioritized transmission of data for Lunar networking
  - QoS provides significant improvement in controlling delay jitter for all traffic types compare to case where no prioritizations are used
- Static QoS configuration works well for CBR-like traffic type (voice, command, telemetry in our scenario)
- Adaptive QoS delivers good jitter for VBR traffic flows (video in our scenario)

- AA performance curves are not smooth; may have convergence issue
  - Result indicate overcompensation of the algorithm
  - Algorithm shows resonance to network size (humps in the performance curves; data point 5 and 9 delivers particular good performance for all metrics)

- Convergence of the algorithm may be affected
  - Initialization: in our study all traffic starts with the TC3 QoS parameter values
  - Consider using the Normal configuration as initialization point may improve convergence
  - AA algorithm measures optimal delay by “temporarily” pushing QoS parameter to the lowest possible; this could disturb the convergence process.
  - Alternative optimal delay measurement or estimation technique should be developed
  - Balance aggressive and relaxed changes by introducing hysteresis
    - E.g., set larger tolerance for ar_diff
    - Voice and Telemetry performance were hit but probably over-compensation to meet AR_PRESET target

- Algorithm trade space not yet fully explored
  - AR_PRESET value for each TC provides control of AA