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PERFORMANCE ANALYSIS OF POLLING MAC'S FOR EXO-ATMOSPHERIC WIRELESS SENSOR NETWORK

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ABSTRACT

In wireless sensor networks a time-variant communications channel can have adverse effects on a system's performance. MAC functionality that addresses the time-varying channel environment, in order to provide reliable data transfer within the network, is essential to ensure mission success. One such network where this becomes apparent is the "Exo-Atmospheric" network. The Exo-Atmoshperic network is composed of nodes in space connected in a star topology and where data transfer within the network is coordinated using a polling MAC. The outlying nodes and the center node ("access point" or "AP") may have different antenna patterns (i.e. dipole or patch), arbitrary time-variant attitudes, and different trajectories. Though the propagation loss may be R^2, the rotation of the nodes coupled with non-isotropic antenna patterns introduces a fading channel between nodes and the access point. Additionally, the network must meet certain prescribed reliability, throughput, and resource requirements. As such this paper presents a performance analysis of using two different polling MAC's for an Exo-Atmoshperic network. The results show the regions where proposed polling schemes – namely Channel Aware Round Robin (CARR) and Channel and Congestion Aware (CCA), will and will not successfully balance given sets of constraints for particular sets of node and network attributes (time-variant attitudes, trajectories, data rates, and antenna patterns).

INTRODUCTION

Considerable amounts of research and development has focused on improving the Quality of Service (QoS) of Wireless LANs (WLAN). The primary method discussed for improving QoS involves managing resources, particularly the wireless channel. For example the IEEE 802.11e standard has been developed specifically to improve the QoS over 802.11b, which is widely used as a WLAN physical/mac layer. 802.11e is meant to address WLAN's that simultaneously provide services to various applications. Especially applications which have inherently different QoS requirements, such as Voice Over IP and streaming multimedia. 802.11e enhances the QoS of the applications it services through the use of priority based scheduling techniques - namely the Enhanced Distributed Coordination Function (Enhanced DCF) and the Hybrid Coordination Function (HCF) [1][2]. Usually the most important QoS metric is delay. As such 802.11e appropriately divides the access time of its applications. Applications with strict QoS requirements are granted access to the wireless channel more frequently, more of the time, or both over lower priority applications.

Other proposed solutions for meeting the necessary QoS of various wireless applications is to employ mechanisms that provide interoperability (switching) between different networks [3]. Examples include the initial user assignment (IAU) and intersystem handover (ISH) both of which provide switching between a WLAN and Universal Mobile Telecommunications System – High Speed Downlink Packet Access (UMTS-HSDPA) [4]. In short interoperability techniques/mechanisms provide greater bandwidth, more capacity, and hence better QoS to the wireless applications it services.

Clearly resource management, particularly access to the wireless channel, is necessary in order for wireless network(s) to meet the QoS requirements prescribed for by various wireless applications.

APPLICATION OVERVIEW

This paper studies possible MAC layer solutions to the Exo-Atmospeheric network. The Exo-Atmospheric network is composed of nodes in space that have some random trajectory, away from the center node or AP. Additionally, the nodes have random attitudes (yaw, pitch,

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and roll rates) and utilize non-isotropic antennas. Each node generates equal amounts of equally important data that needs to be communicated to the AP. Therefore, the QoS requirement of each node is identical.

As discussed above many "data generators" in a WLAN may have different QoS requirements. Hence, complex MAC protocols such as 802.11e are employed to control medium access as the means for ensuring QoS. There are distinct advantages of QoS aware protocols such as 802.11e over non-QoS aware protocols such as 802.11b. However, the advantages are only realized when the network must simultaneously provide service to various applications, each with possibly its own QoS requirements. The cost of implementing such protocols is greater complexity at the MAC layer. In contrast to aforementioned WLAN behavior the Exo-Atmoshperic application requires equal access to the channel. As such this paper considers two simpler polling MAC algorithms, .i.e. the channel-aware round robin polling algorithm (CARR) and the Channel and Congestion Aware polling algorithm (CCA).

As will be shown, in certain instances, the CARR algorithm suffers considerably due to fading in the communications channel. Therefore, the CCA polling algorithm is introduced to negate the effects of the nodes rolling in and out of antennas nulls. This paper will demonstrate the conditions, i.e data rates and number of nodes, for which the CARR algorithm is an adequate solution and where a more "aware" algorithm such as the CCA algorithm becomes necessary.

Both polling techniques were simulated in OPNET© and in an order to make a direct and qualitative comparison between the two techniques simulation attributes for each simulation set (data rate / number of nodes) were as follows.

- The antenna on the AP was isotropic.
- For a simulation set each node in the network had the same antenna.
- All nodes generated the same amount of data at the same time.
- The number of retries was fixed at 6.
- For a particular node its' Roll, Pitch, and Yaw, rates were 1 instance of a uniformly distributed random variables from 0 – 180 deg/sec.
- Each node's trajectory was away from the AP and was 1 instance of a uniformly distributed random variable from 0 – 10 m/sec.

POLLING MAC SUMMARY

The following describes the CARR and CCA techniques studied in this paper. The order of operations for one "round" through the CARR algorithm, assuming *n* number of nodes in the network, was as follows.

- AP sent a Request For Data (RFD) to Node 1.
- If the Signal-to-Noise ratio (SNR) between Node 1 and the AP was above some threshold (SNR Threshold) Node 1 either responded with data or with a No Data Available (NDA) message.
- This process was then repeated for Node 2 through *n*.

The CCA MAC varied from CARR MAC as it included a congestion parameter and polled nodes according to a polling table that's based on node priorities. After the AP had polled each node *x* number of times the AP would re-build the polling table. The polling table was built by first assigning to each node a priority between 1 and 4. Then, for priorities 1-4 a node was placed in the polling table 20, 10, 5, 1 times respectively. The following pseudo code shows how the priority of a node was determined.

```
if (SNR > SNR Threshold) && (Congestion > Congestion Threshold);
node –>priority = 1;

else if (SNR > SNR Threshold) && (Congestion <= Congestion Threshold);
node –>priority = 2;

else if (SNR < SNR Threshold) && (Congestion > Congestion Threshold);
node –>priority = 3;

else if (SNR < SNR Threshold) && (Congestion <= Congestion Threshold);
node –>priority = 4;
```

The SNR Threshold was varied across simulation sets and the Congestion Threshold was set to 5 for all simulation sets. Initially the Congestion Threshold was also varied across simulation sets. However, changing the Congestion Threshold impacted the results minimally, because the polling frequency (rate between successive polls to a node) was always much greater than the data rate at each node. In contrast to CARR, the CCA algorithm considers whether or not a node has been in a null. For a "real" system the Received Signal Strength Indication (RSSI) of the previous communication between an AP and a node would be a reasonable replacement to the SNR metric. Since, RSSI measurements are commonly given by radio manufactures CARR and CCA are easily realizable.

RADIO AND CHANNEL MODEL

In an order to accurately qualify the performance of CARR and CCA it's imperative that the simulation environment accurately model realistic channel and radio behavior. Bit errors were calculated using the probability of a bit error for DPSK modulation which is:

$$P_b = \tfrac{1}{2} e^{-SNR} \qquad (1)$$

Any packet that incurred 1 or more bit-errors failed. Though stringent, it does address the worst-case scenario with respect to packet failures. SNR between the nodes and the AP were calculated for every transmission using the following conventional equation.

$$SNR\,(dB) = P_{TX} + A_{TX} + A_{RX} - P_L - N \qquad (2)$$

Where P_{TX} is the transmit power in. A_{TX} and A_{RX} are the antenna gains for the transmitter and receiver respectively. P_L is the path loss for free space and N is the noise. Other parameters related to modeling the physical layer were:

- Data Rate - 5.5 Mbps
- Center Frequency - 2.4 GHz
- Bandwidth - 22kHz
- Transmit Power - 1W
- Receiver Sensitivity was assumed to be -90 dBm
- Data Packet Sizes were fixed to 1,152 bytes.
- RFD and NDA packets were fixed to 14 bytes.
- Nodes' antenna was either a ½ wavelength dipole or a patch.

PERFORMANCE METRICS

The two metrics of concern for this paper are goodput and average ending queue size. Goodput, as a percentage, was calculated as:

$$GP = \left(\frac{\text{Received Data}}{\text{Data Rate} \cdot \text{Sim. Time} \cdot \text{Number of Nodes}} \right) \cdot 100 \qquad (3)$$

The average ending queue size is simply the sum of the number of packets left in each node queue at the end of the simulation, divided by the number of nodes in the network.

ASYMMETRY

Both CARR and CCA are channel aware algorithms, since, nodes consider their link quality before transmitting data. Being aware of the channel offers distinct advantages over blindly sending data after receiving an RFD. Because the communications link between AP and node is asymmetric. The asymmetric channel is an artifact of different packet sizes, an RFD is 14 bytes and a data packet is 144 bytes. Additionally, the communications channel experiences fading, i.e. nodes with non-isotropic antenna's rotating. Figure 1 depicts the

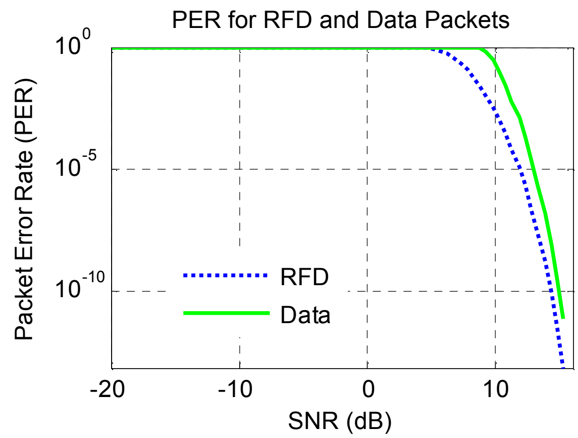

Figure 1. Packet Error Rate for RFD and Data Packets.

error rate associated with data and RFD packets.

The packet error rate varies some between message types, particularly in the region where the communications link may be considered marginal. So, an RFD sent when the link is marginal is more likely to be correctly received than a data packet. Hence, the SNR Threshold parameter was introduced into both CARR and CCA to mitigate the problem of asymmetry. Upon receiving an RFD a node only sends data back if the detected SNR is greater than some SNR Threshold. Figure 2 shows the added benefit, in terms of goodput, gained by including channel awareness in a simple two

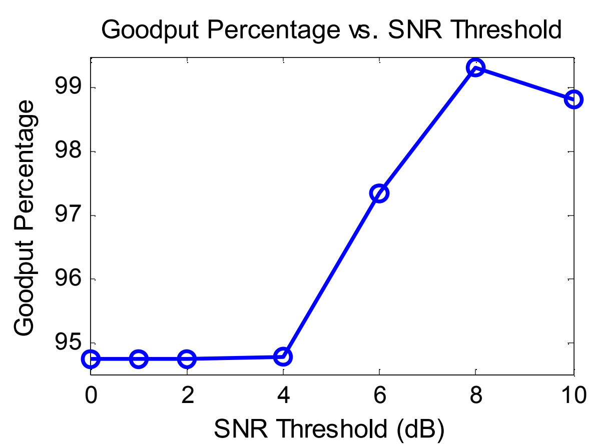

Figure 2. Goodput of 2 node network as a function of SNR Threshold

node network, i.e. Node and AP.

Notice that the goodput slightly decreased after the SNR Threshold value was set above 8 dB. This was because the node didn't send data back to the AP even though the link was good, i.e. above 8 dB.

POLLING MAC RESULTS

The following section summarizes the results of CARR and CCA algorithms for 8 and 12 node Exo-Atmospheric networks. As Figure 3 demonstrates CARR, in terms of goodput, is adequate only over a particular region, i.e. data rate < 200 kbps and SNR Threshold > 5.

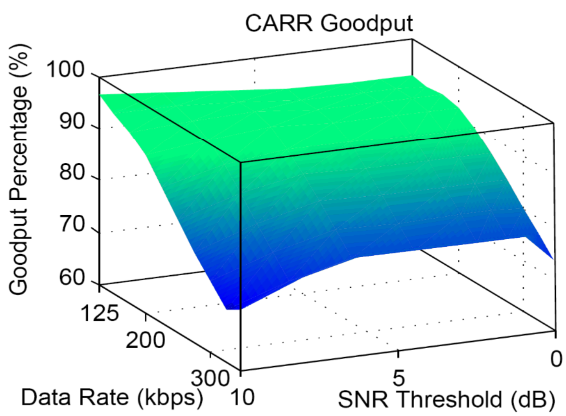

Figure 3. Goodput of 8 node network using the CARR algorithm and patch antenna's at the nodes.

The ending queue size for CARR, as Figure 4 demonstrates, varied considerably with respect to data rate. The number of packets in the nodes' queues at the end of the simulation became larger as the data rate was increased, further indicating the inadequacy of CARR above certain data rates.

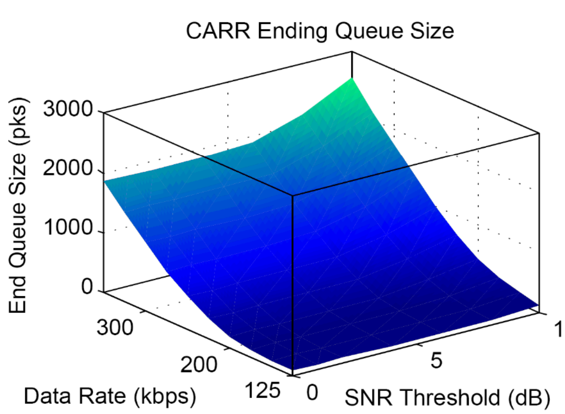

Figure 4. The average ending queue size for 8 node network using the CARR algorithm and patch antennas.

In contrast, as Figure 5 and 6 demonstrate, CCA was much better suited for the 8 node Exo-Atmospheric application.

It provided sufficient goodput over a broader range of data

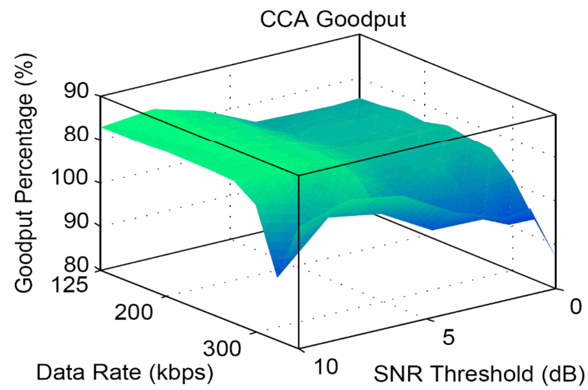

Figure 5. Goodput of 8 node network using the CCA algorithm and patch antenna's at the nodes.

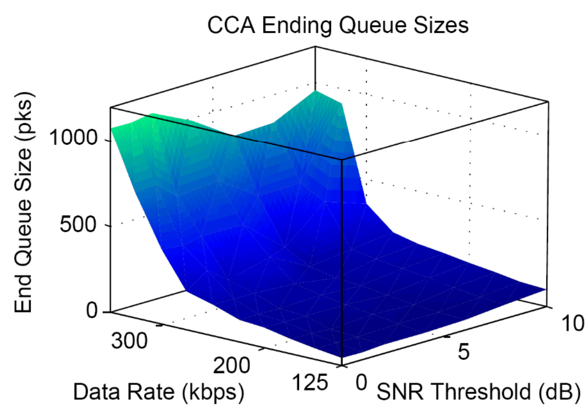

Figure 6. The average ending queue size for 8 node network using the CCA algorithm and patch antennas.

rates (assuming SNR Threshold was set appropriately) and was able to recover quicker then CARR when a node came out of a null. CCA performs better than CARR because it is aware of the congestion of its nodes. As such, when a node becomes congested the AP will query it more often then nodes which aren't congested.

In the simulation sets for which the nodes used dipole antennas both algorithms performed well, when the SNR Threshold was set appropriately, i.e. 5 > SNR Threshold < 8. Since, the communications link between the nodes and the AP was better more of time. This is only true so long as the antenna gains associated with the dipoles "good" regions are sufficiently large enough. Stated otherwise, directivity gain associated with using a patch antenna provided no added benefit because the communications link was nominal for antenna gains greater than 0 dB. The use of dipole antennae improved the performance of the Exo-Atmoshperic network. As such 4 nodes were added to the Exo-Atmospheric network and the simulations sets were performed again for a 12 node Exo-Atmospheric network. As Figures 7 and 8 demonstrate, both algorithms performed considerable better. The added benefit of using dipole antennas, as opposed to patch antennas, has been significant. Evidence of this is further demonstrated in Figures 9 and 10, as the average queue sizes also saw significant improvement. Additionally, for the 12 node case, the CARR algorithm has proven to be adequate for a larger region. This means, that for certain network conditions, CARR is a good and "simple" solution to the Exo-Atmospheric application.

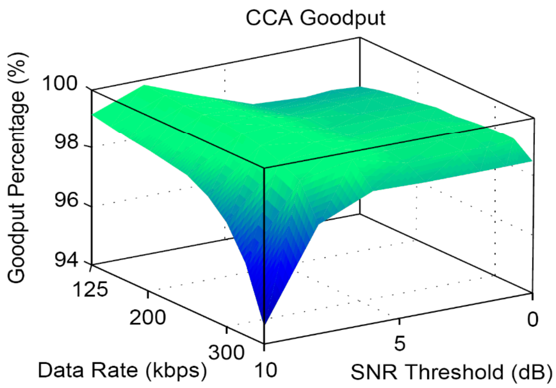

Figure 8. Goodput of 12 node network using the CCA algorithm and dipole antennas.

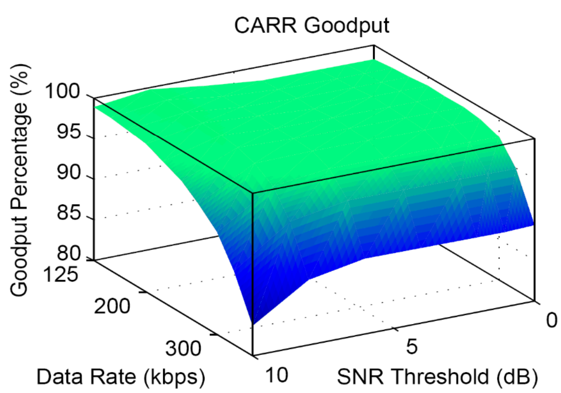

Figure 7. Goodput of 12 node network using the CARR algorithm and dipole antennas.

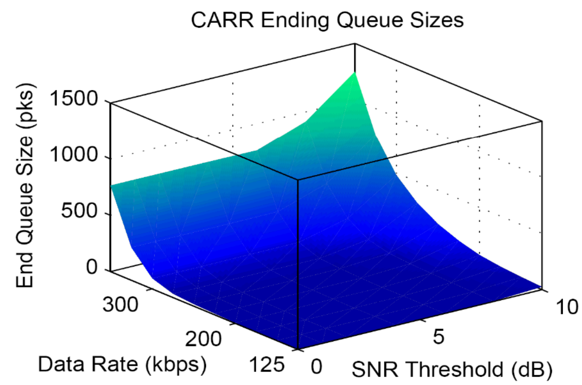

Figure 9. The average ending queue size for 12 node network using the CARR algorithm and dipole antennas.

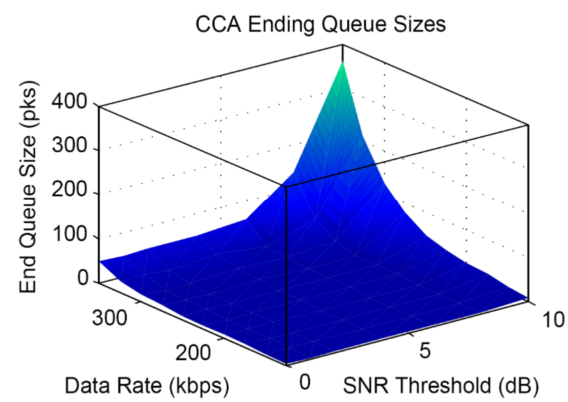

Figure 10. The average ending queue size for 12 node network using the CCA algorithm and dipole antennas.

CONCLUSIONS AND FUTURE WORK

The Exo-Atmospheric application is unique due to the fading that is introduced by node attitudes, trajectories, and non-isotropic antennas. But like many other WLAN's, the QoS that is provided, is a critical measure of the networks performance. In contrast, the nodes in the Exo-Atmospheric application have the same QoS requirement. Therefore, two simple polling algorithms have sufficiently meet the performance objectives. Though CCA covers a broader range of network and node conditions, i.e. antennae, data rates, number of nodes in a network, CARR has also proven just as effective for certain regions.

Although it is not discussed formally in this paper the recovery time, or the time it takes for a node to empty its queue, could also prove to be a critical measure of network performance. This is particularly true for applications that have strict delay requirements, or ending events that may have high priority (critical data). As such, future work will focus on quantifying the recovery time of CCA and CARR algorithms as well as investigating the tradeoffs associated with implementing more complex MAC layer solutions such as 802.11e.

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