Effective Bandwidth Utilization in Wireless Biosensor Networks

R Bhakthavathsalam, SERC, Indian Institute of Science, Bangalore, INDIA.
+91-080-22932940(Tel) +91-080-23602648(Fax) e-mail: bhaktha@serc.iisc.ernet.in ICWN'05

Abstract — Infusing of biosensors with Mobile Ad hoc Networks (MANETs) has led to the emergence of pervasive and intelligent environments, which enhance the activities and interactions of the users supporting a broader class of important applications. The two factors that are of utmost importance in the development of such networks are energy efficiency and bandwidth utilization. Greater emphasis is hence required for the design of newer MAC protocols to maximize net throughput for the available bandwidth. In this paper, we introduce a new concept of circularity by selectively dropping or delaying appropriate control packets in order to obviate the drawbacks of the existing hidden, exposed, blocked and masked node problems inherent in the 802.11 mechanisms. Results are substantiated through NS-2 simulations.

Index Terms — MANET, Multihop, Biosensor, MAC layer, Circularity, Stack Aware.

I. INTRODUCTION

Infrastructure networks comprise of both wireline and wireless types of networks. These are characterized by a largely fixed topology, scalability and stability with sustained sources of power. The most prominent Internet needs a special mention that it is essentially wired, comprising of cables, hubs, routers and gateways and also wireless with loco static satellite links over long ranges. Nowadays, the wireless feature of Infrastructure networks focus on the shift from fixed line computing to computing “on the move”. In a cellular system, the base stations form a wired backbone with constant topology adding mobility of the users with one hop wireless communication feature. Base stations are eternally powered devices with higher range of transmission whereas the end-users have limited power capabilities with shorter radio links. In contrast, each node in wireless mesh networks transmits data to one of its neighboring nodes for continuous connections and reconfiguration around blocked paths by hopping from node to node in its neighborhood until a radio connection can be established. This feature enables the network to be self-healing whenever a node breaks down or a connection goes bad and hence increases network reliability.

Mobile Ad hoc Networks (MANETs) on the other hand are basically Infrastructureless, wherein networks are created and brought down depending on the movement of the devices. MANETs thus present a highly dynamic scenario where the topology is unpredictable due to the inherent nomadic behavior of the end-hosts. MANETs are generically composed of nodes, which are in turn both end-hosts and routers. The dual functionality of the nodes thus enables these types of networks to be used in areas where there is little or no prior infrastructure setup [1], [2]. However, a large number of challenges are thrown up with these dynamically changing topologies and multihop connectivities, the primary issues being routing and medium access with special emphasis on power consumption and bandwidth utilization [3], [4].

Yet another advancement closely akin to MANETs is in the field of wireless biosensor network. Unlike MANETs, generally the sensor networks have an additional role of sensing the surrounding environment where they are ingrained. The emphasis here is not only on computing and transmitting data but also on reading the required data, and subsequently processing and communicating it accordingly. Data acquisition is the primary task of sensors. Sensors are of primarily two types: Electronic sensors of micro level and Biosensors of nano scale. Passive biosensors are mainly used to detect information regarding a physiological change in the presence of various chemicals or biological materials in the environment. Active biosensors are live biological entities in conjunction with special types of microelectronic units that can be visualized as the nodes of a wireless biosensor network. Interactions between the nodes of such a biosensor network are sustained among these chosen entities by their intrinsic distributed communication abilities. The prominent features of wireless biosensor networks are depicted in the block diagram.

II. WIRELESS BIOSENSOR NETWORKS

The increasing miniaturization of sensors using advanced nano technology has paved the way for the development of biosensors. Biosensor is a compact analytical device incorporating a biological or biologically derived sensing element or its analog, either integrated within or intimately associated with a physicochemical transducer [5]. Interfacing at nano level causes change in the properties of a nano object. Thus the direct incorporation of biological entities in current microelectronic components is generally difficult, if not impossible [6]. Biosensors are made to effectively integrate a
biological analyte with an electronic component to yield a measurable signal. A major advancement in this direction is the development of Mote technology. Motes are nothing but tiny, self-contained computers powered by battery and having radio links, which enable them to communicate between one another. This ability of exchanging data enables them to self-organize into ad hoc networks and thus they form the building blocks of sensor networks. The sensor and the mote together form the end nodes in sensor networks or the mobile hosts in MANETs [7].

Overall, the relation between sensor and ad hoc networks becomes clear if we view these nodes as a constituent of the broader class of MANETs. Both these types of networks have similar applicability and characteristics with the underlying backbone of their structure being the same [8]. MANETs provide access to pervasive computing continuously at all locations on the globe. Biosensors can be incorporated in devices, machines and even attached to human body thereby making it applicable in innumerable situations. Thus the emergence of wireless biosensor networks made pervasive computing possible both at macro level and micro/nano world. They find applications in niche areas like healthcare management systems, biometrics, drug detection, measurement of different concentrations of specific bacteria and hazardous chemicals and even measure acidity levels, inventory location awareness, mine and explosive detection, determination of various chemicals or biological materials in the environment, seismic and structural monitoring, both in indoor/outdoor surveillance etc.

As a theoretical model, let us consider a hybrid situation of a super specialty hospital under medical tourism. For example, four patients of different nature of diseases are selectively attached with the respective biosensors over their body for observation and monitoring; breast cancer patient with ultra sensitive DNA/RNA biosensor, diabetic patient with glucose biosensor, heart patient with pacemaker, kidney patient with label probe for ligand/protein detection and four of the respective specialists with interactive devices forming eight mobile hosts of a wireless biosensor network constantly communicating in a fixed range of the pervasive computing environment. The set of challenges in developing such complex network and evaluating its performance metrics are diverse. Only the stack aware features of MAC sublayer for such a wireless network with effective utilization of the available bandwidth are given major attention in this paper.

III. STACK AWARE MAC LAYER

The present OSI reference model has been designed primarily for fixed networks largely comprising of the Internet, which in turn uses the four layer TCP/IP model. Emerging wireless and ad-hoc networks have also been modeled based on this layered concept, which however has thrown up some basic challenges. Dynamically changing network topologies and the absence of a sustained source of power in MANETs with increased routing framework requirements have resulted in the need of developing a “Stack Aware” architecture especially for these types of ad-hoc networks. In such architecture, each layer should be aware of what the other layers do and the functionalities in a particular layer are highly optimized for usage with other layers. Physical layer aspects are however not dealt with too deeply.

The network and link layers are the two primary layers where effective enhancements need to be made to fully implement the above-mentioned Stack Aware features for MANETs. Routing protocols for these dynamic scenarios have been dealt with in our earlier work wherein the Proximate Runner Protocol was notably designed with many advantages bringing about a remarkable improvement in protocol performance [9]. Presently, here we concentrate on the Medium Access sublayer of the Data Link layer. It has been seen that the practical capacity of ad hoc networks happens to be quite low, largely due to interference and the behavior of the IEEE 802.11 protocol. As the density of the nodes increases, so does the interference. For a transaction to take place, Request-To-Send (RTS) and the Clear-To-Send (CTS) dialogue is implemented here to enable two nodes to start communicating with each other. However, due to interference and other factors, these control packets may be lost or garbled hence delaying communication between the nodes. The fullest use of available bandwidth is curtailed by the hidden, exposed, blocked and masked node problems inherent in 802.11 mechanisms.

Our goal here is hence to take note of the fact that an increase in the density of the nodes leads to degradation in throughput as interference increases. An implicit goal in of any MAC protocol is to minimize collisions, raise throughput and prove stable. The two factors, which are of utmost importance in the development of newer MAC protocols, are energy efficiency and bandwidth utilization. Emerging solutions to the Energy problem have been proposed which are independent of the underlying routing protocol and hence they fail to optimize performance for any particular routing framework. Another major factor is also optimizing bandwidth utilization. Bandwidth is a scarce resource and needs to be properly managed if we are to maximize net throughput. Common solutions include splitting the available bandwidth into the two channels: one exclusively for control packets and the other for data packets. The ratio of this division has to be optimal to ensure increased throughput even though this scheme is largely dependent on the channel contention mechanism in use by the protocol. We thus realize that an effective MAC protocol goes a long way in ensuring better network performance, which acts as our primary objective to improve upon the current IEEE 802.11 protocol in terms of throughput and thereby bandwidth utilization.

IV. NEW PARADIGM OF RTS/CTS MECHANISM

Our RTS/CTS exchange model basically concentrates on two aspects concerning the transfer of these control packets from one node to another before the actual communication begins. The RTS/CTS mechanism is used to avoid data packet collisions due to the hidden node problem as defined in
shown in Fig. 2. The costly Data/Ack packet collision does not take place. The chance to complete their ongoing operation so that they a packets of its neighboring nodes. We give these nodes a packet transfer at that point and may not have heard the RTS nodes. These nodes may be in the process of data or control into consideration the immediate neighbors of the current data exchange. By delaying CTS transmissions we are take delaying the actual transfer of packets in the immediate context leads to lower net throughput. On one hand, we may be refrain from transmissions leading to costly data packet collisions. The time taken to transmit the additional RTS packets is a necessary sacrifice being made which is however relatively insignificant. The same circularity concept is used to delay select CTS packets. Presently we have only delayed CTS packets by one SIFS time in our experimental setup. In a normal exchange, after the RTS and CTS packets have been transmitted, all the neighboring nodes are put to sleep to ensure that they do not interfere in the soon to be followed data exchange. By delaying CTS transmissions we are take into consideration the immediate neighbors of the current nodes. These nodes may be in the process of data or control packet transfer at that point and may not have heard the RTS packets of its neighboring nodes. We give these nodes a chance to complete their ongoing operation so that they a costly Data/Ack packet collision does not take place. The timeline diagram incorporating CTS delay characteristic is shown in Fig. 2.

The circularity concept is implemented for the above-mentioned reasons but we should also consider the exact values of these circularity value pairs. With increasing values, lesser number of RTS and CTS packets are dropped or delayed thereby making the system converge to a steady state. With these greater circularity values, the inherent behavior of the system models itself on the 802.11 protocol since all other mechanisms, like the channel contention, transfer latencies etc all remain essentially the same. This view is substantiated by our simulation results, which show that after an initial period of restlessness (due to the greater number of drops/delays) the algorithm settles down to a sustained level of throughput. After a certain threshold circularity value is reached, the net throughput attained becomes constant as the number of drops and delay of RTS and CTS packets become few and far between.

V. TIMELINE ANALYSIS

Timeline Analysis for dropping RTS packets with circularity: It is examined by taking some test circularity values 2, 3, and 4 and it is seen how RTS-CTS mechanism works with different circularity values. Some notations are as given below

** refers to the cases where the dropping of one or more RTS packets due to circularity gives chance for another RTS packet to make its way through, without any collision. For such cases we gain on throughput in two ways:
   a) It avoids a certain collision and hence it reduces the time lost due to collision.
   b) It allows one RTS packet to make its way through, without any collision and hence this extra RTS packet adds to the throughput.

* refers to the cases where the dropping of more than one RTS packets would lead to no RTS packet transmission.

# refers to the case where the only RTS packet at that particular time would lead to a loss of RTS packet and hence these cases decrease the throughput.

Let t_c be the time lost due to collision and t_r be the time for retransmission of RTS. So t_r > t_c.

When circularity = 2, we observe the occurrence of 8 **, 6 * and 1#. Therefore time saved due to RTS-CTS with circularity is computed as

\[8(t_c) + 6(t_c - t_r) - t_r = (14 t_c - 7 t_r)\]

Therefore, an additional 7 RTS packets are transmitted.

When circularity = 3, we have 5 **, 4 * and 1#. So time saved due to RTS-CTS with circularity is

\[5(t_c) + 4(t_c - t_r) - t_r = (9 t_c - 5 t_r)\]

In this case an additional 4 RTS packets are transmitted

When circularity =4, we have 3 ** and 2 *. So time saved due to RTS-CTS with circularity is

\[4(t_c) + 2(t_c - t_r) = (6 t_c - 2 t_r)\]

The gain of 4 RTS packets is achieved

![Fig 2. Timeline Diagram of New RTS/CTS Mechanism.](image-url)
The above timeline analysis gives a clear picture of how the number of MAC collisions avoided and number of RTS packets lost fluctuate with different values of circularity.

Timeline Analysis for delaying CTS packets with circularity:

Similar notations used in the analysis:

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Timeline Analysis for delaying CTS packets with circularity: Similar quantitative analysis of the Enhanced RTS-CTS mechanism by delaying the CTS packets is carried out in comparison with the present MAC 802.11 protocol.

Notations used in the analysis:

A. The time taken for the completion of one transmission between two nodes in the MAC 802.11 protocol is given by:

\[ T_{m} = T_{DIFS} + T_{RTS} + T_{SIFS} + T_{CTS} + T_{DATA} + T_{SIFS} + T_{ACK} \]

The next step is to compare \( T_{m} \) and \( T_{e} \):

\[ T_{m} = 2T_{m} \ldots (1) \]
\[ T_{e} = T_{m} + 3T_{DIFS} \ldots (2) \]

\[ T_{e} = T_{DIFS} + T_{RTS} + T_{CTS} + T_{DATA} + T_{ACK} + 3T_{SIFS} \]

\[ T_{g} = T_{RTS} + 3T_{DIFS} \]

\[ T_{m} = T_{DIFS} + T_{RTS} + T_{CTS} + T_{DATA} + T_{ACK} + 3T_{SIFS} \]

The time taken for a minimum of two node pairs is much greater in the MAC 802.11 protocol as compared to that in the Enhanced RTS-CTS protocol. Thus the enhanced mechanism takes lesser time for two-node pair communication as compared to the existing MAC 802.11 protocol.

C. Further for three node-pair communication,

\[ T_{e1} = T_{te} = T_{e} \]
\[ T_{ml1} = 3T_{m} \]

By similar arguments, again it is verified that

\[ T_{e} \ll T_{m} \]

Therefore we see that by using the Enhanced protocol, communication will take the same amount of time as that for a single node pair or two node pairs or even more. This is so because this protocol is designed for parallel transmission. While the first node pair communication is going on, the protocol allows other pairs to communicate as well. Thus the time taken for a minimum of two node pairs is much greater in the MAC 802.11 protocol as compared to that in the Enhanced RTS-CTS mechanism. The time that is saved can be utilized for other transmissions.

VI. SIMULATION RESULTS

Let us consider the 8-node scenario for the simulation studies. The Network Simulator version 2.27 (NS-2) is used with appropriate changes made to -mac/mac-802_11.cc file. The pair of values of the RTS and CTS circularity has been assigned differently in two steps. In the first instance, both the RTS and CTS circularities are varied simultaneously. From the graph obtained here, we observe the circularity value for which one gets maximum throughput. Now keeping this value of RTS circularity fixed, the CTS circularity is varied to obtain the optimum throughput. This RTS and CTS circularity value pair.
denotes the optimum values for which the maximum throughput is attained. The results of different values of circularity are shown in the graph.

In Fig.3 we observe that the throughput keeps oscillating with the increase in the respective circularity values for both the RTS and CTS control packets. However, what is of primary significance is the circularity value of RTS for which the net throughput attains maximum.

Fixing the circularity value for RTS at the peak found in the earlier graph, ie 27, now the CTS circularity is varied. It is found overall that the throughput for our mechanism is greater than that of the standard one as depicted in Fig. 4.

VII. CONCLUSION

The formation of the mobile host in the hypothetical model of the wireless biosensor network by combining the sensing element and the processing and transmitting device has been tacitly assumed. The inherent problems associated with the MAC sublayer are initially analyzed by cursorily estimating the time taken for single transaction. The consequent events caused by the dropping of RTS and delaying CTS selectively using different circularity values are visualized. These events yield better utilization of the available bandwidth by enhancing the contention resolution for the overall medium access to the mobile hosts. The results of the enhanced RTS - CTS mechanism of circularity are substantiated through NS-2 simulations for the assumed scenario of eight-node wireless biosensor network.

VIII. REFERENCES


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