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MAC Power Enhancement Using Overlapped Carrier Sense Multiple Access

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Abstract

In wireless adhoc networks, multihop routing may result in a radio knowing the content of transmissions of nearby radios. This knowledge can be used to improve spatial reuse in the network, thereby enhancing network throughput. Consider two nodes A and B which are neighbors in a WANet not employing spread-spectrum multiple accesses. Suppose node A transmits a packet to node B for which node B is not the final destination. Later, node B forwards that packet on to the destination. Any transmission by node B not intended for node A usually causes interference that prevents node A from receiving a packet from any of neighbor nodes. This increases the overall time delay in transmitting packets over the network. However, if node B is transmitting a packet which it had previously received from node A, then node A knows the content of the interfering packet, and this knowledge can allow node A to receive a packet from one of neighbors node during node B's transmission.

In wireless sensor networks and ad hoc networks, energy uses are in many cases the most important constraint since it corresponds directly to operational lifetime. It's due to their remoteness; it makes inability to resupply power to these energy-constrained devices. Therefore to extend a wireless sensor network's effectiveness, the lifetime of the network must be increased by making them as energy efficient as possible. An energy-efficient medium access control (MAC) and routing protocol can maximize the whole network lifetime.

This paper focuses on a protocol stack solution that deals with MAC layer and Network layer, which minimizes the energy consumption and delay required to transmit packets across the network. We propose how the 802.11 MAC protocol can be modified to allow for transmissions to be overlapped by taking advantage of noncausal knowledge of interfering signals. The resulting overlapped CSMA(OCSMA) with An Adaptive Energy Efficient MAC Protocol improves spatial reuse and end-to-end throughput in several scenarios and also which minimizes the energy consumption.

Key Words: *Energy-efficient medium access control , Overlapped Carrier Sense Multiple Access, wireless sensor networks*

1. INTRODUCTION

Wireless networks present several challenging issues for the network designer that are quite different from their wired counterparts. An impairment that results due to the broadcast nature of the wireless network is interference. Since all the nodes share the same physical medium, simultaneous transmissions may result in interference at the receiving nodes. In networks that do not employ code-division multiple access, medium-access control (MAC) protocols are used to allocate the channel resources to specific transmitters and receivers so as to minimize the interference in the network. Traditionally, the design of the MAC protocol is carried out independently of the physical-layer design, assuming a simplistic collision channel model. These models assume the channel to be noiseless, and a packet is successfully received by a node if there are no other transmissions in its interference range. These MAC protocols schedule transmissions such that the collisions in the network are minimized.

Multi-user detection (MUD) in wireless networks has been proposed by several authors [1] as a means to increase spatial re-use by increasing the number of simultaneous transmissions in the network. MUD techniques are employed at the physical layer to recover information from colliding packets at the receiver. These signal processing techniques used at the physical layer enable a node to receive packets in the presence of other transmissions in its communication range. This multipacket reception (MPR) capability of the nodes at the physical layer leads to greater spatial re-use in the network. MAC protocols were proposed in [5], [8] that take advantage of the MPR capabilities of the physical layer to increase the spatial re-use in the networks to provide high throughput in heavy traffic and low delay in light traffic.

However, in most cases, mobile radios might not have sufficient processing power to perform complex MUD schemes. The complexity of the MUD schemes could be significantly simplified and the performance enhanced if the interfering signal were completely known at the receiver. In wireless ad hoc networks, the interfering signal may be known at the receiver due to multihop routing. For example, consider a four-node linear network consisting of nodes A, B, C and D, where A transmits a packet to D using multihop routing. In a slotted communication system employing conventional MAC protocol, a typical sequence of transmissions for a packet would be

1 : A → B; 2 : B → C; 3 : C → D;

Where the notation 1: A → B indicates that node A transmits a packet to node B in time slot 1, etc. Under conventional MAC protocols, in the time slot when C forwards a packet to D, A is not allowed to transmit to B since C's transmission will cause interference at B. However when a MPR-based MAC protocol is employed, simultaneous transmissions of A→ B and C→ D are possible, since MUD techniques can be employed at B to recover the packet transmitted by A. Note that the packet transmitted by C to D is the same packet that B forwarded to C in an earlier time slot (ignoring the differences in the headers). If B were to retain a copy of the packet that it forwarded to C, B would have information regarding the interfering transmission. This greatly reduces the complexity of the MUD algorithms employed at the PHY to recover the packet transmitted by A.

The idea of employing known-interference cancellation (IC) techniques to increase simultaneous transmissions in ad hoc networks was first analyzed in [9], Knowledge of the interfering signal is assumed at both the transmitter and the receiver, and the receiver performs MUD/IC to recover additional messages. Limitations on scheduling such simultaneous transmissions were analyzed and a MAC protocol that supports such simultaneous transmissions was proposed.

The idea of employing network coding to increase spatial re-uses and throughput in wireless ad hoc networks has recently received considerable attention from the research community [10]. A transmitting node exploits the broadcast nature of the physical medium along with the knowledge of the interfering messages at the receiving nodes to combine/encode multiple independent messages at the network layer and transmit to several nodes. A node receiving the encoded message uses the knowledge of the other interfering messages, available at the network layer, to recover the message intended for it. Practical channel sharing schemes that support network coding in wireless ad hoc net-works were proposed in [11] The idea of employing network coding at the physical layer to increase simultaneous transmissions in wireless ad hoc networks was considered in [17]. A node receiving a signal consisting of several simultaneous transmissions employee the knowledge of the interfering signals, available at the physical layer, to recover the message intended for it. This approach is similar to the idea of employing MUD with known interference cancellation. These works analyze the physical-layer aspects involved, but do not address the MAC-layer implications of employing such simultaneous transmission schemes. We analyze some of the fundamental limits involved in employing MUD/IC based techniques to accommodate simultaneous transmissions in the network. Our analysis provides an understanding of the performance gains of such transmissions, and an insight into the PHY and MAC interaction required for scheduling such transmissions.

Wireless networks are used in a wide range of applications to capture, gather and analyze live environmental data. A wireless sensor network typically consists of a base station and a group of sensor nodes. The sensor nodes are responsible for continuously sampling physical phenomena such as temperature and humidity. They are also capable of communicating with each other and the base station through radios. The base station, on the other hand, serves as a gateway for the sensor network to exchange data with applications to accomplish their missions. While the base station can have continuous power supply, the sensor nodes are usually battery-powered. The batteries are inconvenient and sometimes even impossible to replace. When a sensor node runs out of energy, its coverage is lost. The mission of a sensor application would not be able to continue if the coverage loss is remarkable. Therefore, the practical value of a sensor network is determined by the time duration before it fails to carry out the mission due to insufficient number of "alive" sensor nodes. This duration is referred to as the network lifetime. It is both mission-critical and economically desirable to manage sensor data in an energy-efficient way to extend the lifetime of sensor networks.

In addition, many techniques used in wireless networks do not scale well and therefore would not be appropriate for a WSN which may need hundreds or even thousands of nodes to be useful. Limiting the number of nodes per unit area limits the resolution of any data the sensor nodes are designed to capture. A small number of nodes in a large area do not have the same resolution as a large number of nodes in the same area. Furthermore, networks that do not scale well tend to consume more energy due to their inefficient use of resources. Such networks will consist of large numbers of distributed nodes that organize themselves into a multi-hop wireless network. Each node has one or more sensors, embedded processors, and low-power radios, and is normally battery operated. Typically, these nodes coordinate to perform a common task.

In this work our focus on a protocol stack solution that deals with MAC layer and Network layer, which minimizes the energy consumption and delay required to transmit packets across the network. We propose how the 802.11 MAC protocol can be modified to allow for transmissions to be overlapped by taking advantage of non causal knowledge of interfering signals. The resulting overlapped CSMA(OCSMA) with An Adaptive Energy Efficient MAC Protocol improves spatial reuse and end-to-end throughput in several scenarios and also which minimizes the energy consumption.

The rest of the paper is organized as follows. Section II introduces the idea of employing overlapped transmission in a linear network Section III describes the OCSMA MAC protocol. Section IV describes the system model and gives some basic definitions An Adaptive Energy Efficient MAC Protocol. The paper is concluded in Section V.

2. OVERLAPPED TRANSMISSION IN A LINEAR NETWORK

In this section, we illustrate the idea of overlapped transmissions in a four-node linear network, which is illustrated in Fig. 1. We assume that the nodes can communicate only with the adjacent nodes and operate in the half-duplex mode. Node A transmits packets to node D through multihop routing. A typical transmission sequence under a conventional scheduling scheme is depicted in Fig. 1, in which it takes three time slots for a packet from A to reach D. The scheduled transmissions in a given time slot are marked by solid directed arrows along with the packet identifiers, and the interference caused by these transmissions are marked by dashed arrows. Under typical carrier-sense multiple access protocols with collision avoidance (CSMA/CA), when packet m_1 is being forwarded by C in time slot t_3 , A cannot transmit the message m_2 since C's transmission will cause interference at B. The throughput of this network can be improved by employing simultaneous transmissions as described below. We observe that in the time slot t_3 , C forwards the packet m_1 which it received from B in the earlier time slot t_2 . If B were to retain a copy of the message m_1 locally, it knows the message being transmitted by C in time slot t_3 (assuming that link-level encryption is not used and any differences in the headers are ignored). If A is allowed to transmit the message m_2 in the time slot t_3, B can use the stored information regarding m1 to mitigate the interference caused by C's transmission. We call this additional transmission that results due to the interference mitigation of known interference as overlapped transmission.

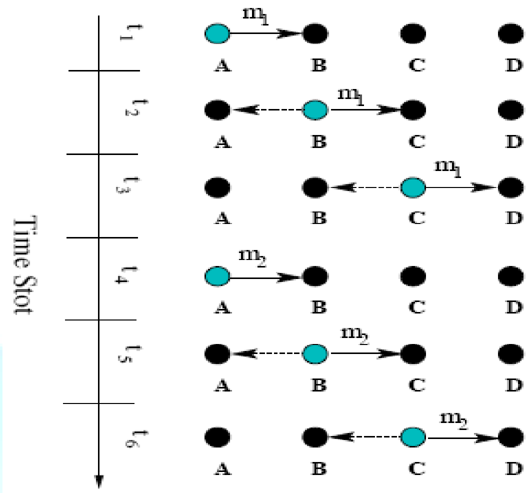

Fig. 1.Four-node linear network with conventional scheduling.

A scheduling scheme employing the idea of overlapped trans-mission for the four-node linear network is depicted in Fig. 2. Under this scheduling scheme, a packet is transmitted from A to B employing overlapped transmission strategy during the time slot that C forwards a packet to D. Since the transmission of the packet from A to B did not involve the allocation of a separate time slot for its transmission, a packet requires on an average only two time slots to be transmitted from A to D. These two time slots are required for the scheduling of transmissions from B to C, and C to D, respectively.

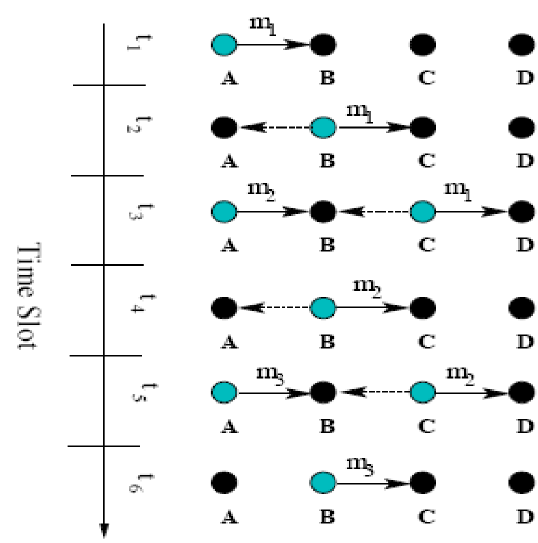

Fig. 2 Four-node linear network with overlapped transmissions.

A scheduling scheme employing the idea of overlapped trans-mission for the four-node linear network is depicted in Fig. 2. Under this scheduling scheme, a packet is transmitted from A to B employing overlapped transmission strategy during the time slot that C forwards a packet to D. Since the transmission of the packet from A to B did not involve the allocation of a separate time slot for its transmission, a packet requires on an average only two time slots to be transmitted from A to D. These two time slots are required for the scheduling of transmissions from B to C, and C to D, respectively.

3. OVERLAPPED CARRIER SENSE MULTIPLE ACCESS PROTOCOL

The OCSMA protocol is based on the distributed coordinated Function (DCF) mode of the IEEE 802.11 MAC protocol unless stated explicitly, the terminology used in the following sections reflects the MAC protocol description of the IEEE 802.11 standard.

The design of the OCSMA protocol is best described with the Example network of Fig. 3(a). The timeline of the protocol for the example network is shown in Fig. 4, and the frame formats are shown in Fig. 5. The operation of the protocol can be divided into five phases as follows:

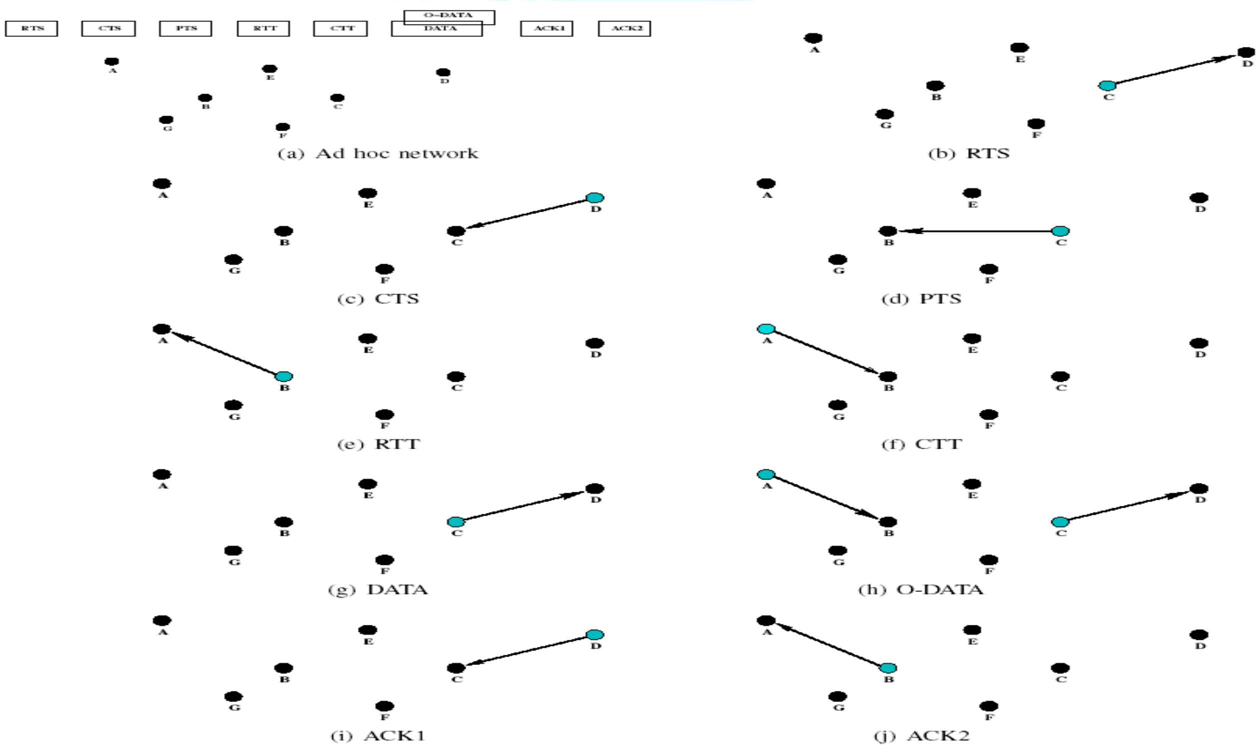

Fig. 3.Typical frame exchanges in OCSMA protocol.

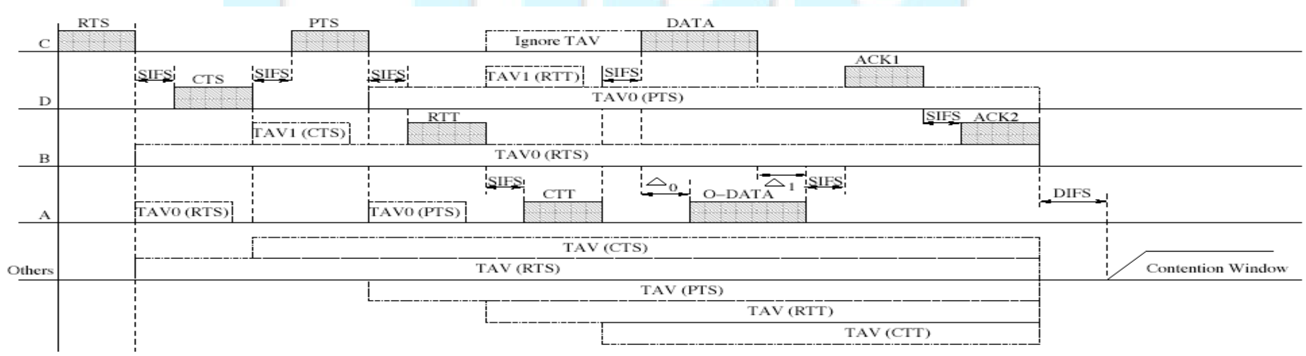

Fig. 4.Timeline of the OCSMA protocol

3.1 Primary Handshaking

This phase of the OCSMA protocol is similar to the RTS/CTS exchange of the IEEE 802.11 protocol. When a node has data to transmit to another node in its transmission range, it initiates the handshake by sending a Request To Send (RTS) frame. The node that receives the RTS sends a Clear To Send (CTS) frame if it senses the medium to be free. The node initiating the handshake is the primary transmitter and the node that responds to the RTS is the primary receiver. All the other nodes that receive the handshake set their transmit allocation vectors (TAV) for the duration of the transmission. The transmit allocation vector is similar to the network allocation vector (NAV) defined in the IEEE 802.11 standard. However, as described below there are some significant differences between them.

The MAC of each receiver is equipped with a transmit allocation matrix (TAX) which is responsible for the virtual carrier sense mechanism. The TAX is an array of several transmit allocation vectors (TAV).). Nodes receiving a valid frame that is not destined for them update their TAV with the information in the Duration/ID field. Unlike the NAV vector of IEEE 802.11, the TAX allocates a TAV for each valid frame (not addressed to the receiving node) it receives, even if the new TAV value is not greater than any of the current TAVs. Thus the TAX maintains an array of TAVs for each frame that it receives. The medium is considered busy if any of the TAVs is set. The TAVs also store information regarding the transmitter and receiver of the frame, if that information is available. The implementation of the TAX greatly simplifies the design of OCSMA protocol, as discussed in later sections. Another important distinction between NAV and TAV is that a node can transmit even if the TAV of a node is set.

Consider the wireless ad hoc network shown in Fig. 3(a), whereat some point of time, node C intends to forward a packet to D that it has received from B in an earlier transmission. C transmits an RTS to D, and D responds with a CTS. The primary handshaking phase is depicted in Figs. 3(b) and 3(c).

3.2 Secondary Handshaking

The secondary handshaking can be thought of as a secondary/CTS exchange employed to determine the possibility of an overlapped transmission during the present transmission interval. Upon receipt of the CTS, the primary transmitter sends a Prepare

To Send (PTS) frame to the node from which it received this particular data frame in an earlier transmission. If the data is

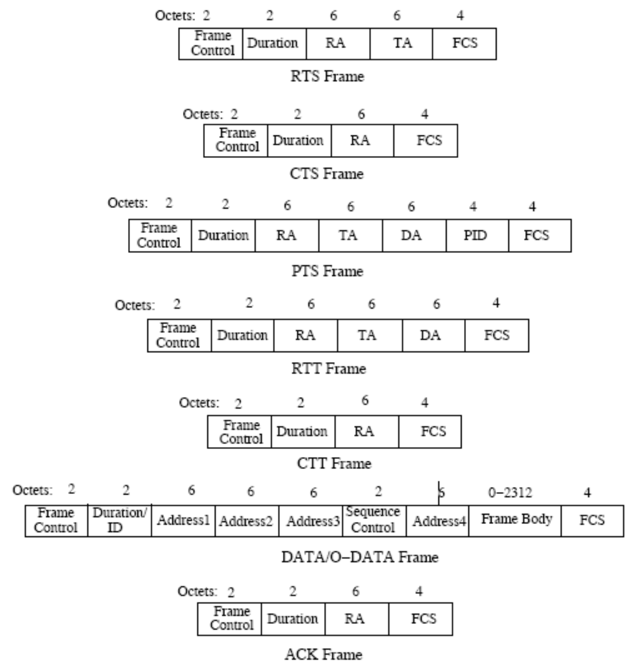

Fig. 5. Frame formats of the OCSMA Protocol

Locally generated, no PTS is sent and transmission of the data frame starts after SIFS, as in the 802.11 protocol. If the PTS is sent, the primary transmitter defers transmission of the data frame until the completion of the secondary handshaking. The TAX ensures that none of the TAVs of the primary transmitter are set by the control frames corresponding to the secondary handshaking initiated by this node.

In the network of Fig.3(a), consider a transmission in which node C forwards to D a data frame that it previously received from B. After the completion of RTS/CTS exchange with D, C sends a PTS to B.

The PTS frame format is shown in Fig. 5. The format is similar to the format of an RTS frame except for the additional fields DA and PID. DA contains the address of the primary receiver and PID contains the unique ID of the data frame that is being transmitted to the primary receiver. The node receiving the PTS frame is called the secondary receiver. Being a secondary receiver implies that the present node has information regarding the primary transmission and is capable of receiving an overlapped transmission.

Upon receipt of the PTS, the secondary receiver ensures that its TAV is set only by the primary transmitter. Note that the TAVs store information regarding the transmitter and receiver of any valid frame it receives that is not addressed to the receiving node. This is to ensure that there are no other transmissions occurring in the range of the secondary transmitter except for the primary transmission. If this is true, it identifies a suitable partner for secondary transmission as described below.

Once the secondary receiver identifies the medium to be free except for the primary transmission, it generates a list of potential partners. The nodes are identified based on the following criteria:

1) The node should not be in the transmission range of the primary receiver.
2). The node should have transmitted a frame to the secondary receiver in an earlier time slot. The information regarding receipt of frames from all the other nodes is maintained in a cache at the MAC.

3.3 Primary transmission

A timer at the primary transmitter is set to expire in synchronous with the completion of the secondary handshaking. Note that its TAV timer will not be set during the transmission of the secondary handshaking (refer to the TAV settings of node C in Fig. 4). We note that this differs from the typical NAV vector implementation of IEEE 802.11 protocol. When the timer expires, it commences the transmission of the data frame to the primary receiver. This is shown in Fig. 3(g).

3.4 Secondary transmission

After the transmission of the CTT frame, the secondary transmitter starts a timer such that it expires Δ0 seconds after the commencement of the primary transmission. This overlapped delay Δ0 is a design parameter which results in a delayed trans- mission of the secondary transmission. This delay between the primary and secondary transmissions is intended for the secondary receiver to acquire the signal from the primary transmitter. The value of this overlapped delay is chosen based on the physical layer (PHY) parameters such as the Physical Layer Convergence Protocol (PLCP) header length such that the signal from the primary transmitter can be acquired by the secondary receiver. Note that the design of this delayed transmission of the overlapped data doesn't ensure perfect synchronization of both the primary and secondary transmissions at the secondary receiver. However, this delay ensures that the secondary receiver acquires the signal of the primary transmitter which greatly simplifies the interference cancellation (IC) mechanism at the PHY layer. The format of the overlapped data (O-DATA) frame is same as the data frame. The secondary receiver cancels out the interference and recovers the overlapped data. This phase is illustrated in Fig. 8(h). Note that the secondary transmission is allowed to terminate Δl seconds after the end of the primary transmission.

3.5. Data Acknowledgments

After the DATA and O-DATA are successfully received, the primary and secondary transmitters acknowledge the successful reception of the primary and overlapped data frames as shown in Figs. 3(i) and 3(j), respectively.

First, consider the successful reception of the DATA and O-DATA frames at the primary and secondary receivers. These nodes contend for the channel access if they have packets to transmit. The channel access mechanism for the primary receiver is the same as the mechanism in the IEEE 802.11 protocol. How- ever, the channel access mechanism for the secondary receiver is slightly different. If the secondary receiver is forwarding the current O-DATA frame, and finds the medium to be free, it starts its backoff timer with the contention window (CW) size twice the current CW value (at the secondary receiver). This ensures that, with high probability, the secondary receiver is in backoff for a greater duration than the primary receiver. Hence, the secondary receiver will not contend with the primary receiver for channel access.

Next, consider the reception of acknowledgments at the primary and secondary transmitters. Upon reception of ACK, the primary transmitter resets it contention window (CW) parameter as in the IEEE 802.11 protocol. If it has a packet to transmit, the channel access mechanism is same as the mechanism in the IEEE 802.11 protocol. However, the secondary transmitter does not reset its CW. This ensures that, with high probability, the secondary transmitter does not contend with the primary trans- mitter for channel access. The CW parameter of the secondary transmitter is reset when it receives an ACK for any DATA frame that it transmits later. We observed that, in networks with linear flows, this design leads to a greater probability of overlapped transmission.

4. AN ADAPTIVE ENERGY EFFICIENT MAC PROTOCOL

Wireless sensor networks are used in a wide range of applications to capture, gather and analyze live environmental data [12], [13]. A wireless sensor network typically consists of a base station and a group of sensor nodes. The sensor nodes are responsible for continuously sampling physical phenomena such as temperature and humidity. They are also capable of communicating with each other and the base station through radios. The base station, on the other hand, serves as a gateway for the sensor network to exchange data with applications to accomplish their missions. While the base station can have continuous power supply, the sensor nodes are usually battery-powered. The batteries are inconvenient and sometimes even impossible to replace. When a sensor node runs out of energy, its coverage is lost. The mission of a sensor application would not be able to continue if the coverage loss is remarkable. Therefore, the practical value of a sensor network is determined by the time duration before it fails to carry out the mission due to insufficient number of "alive" sensor nodes. This duration is referred to as the network lifetime [12]. It is both mission-critical and economically desirable to manage sensor data in an energy-efficient way to extend the lifetime of sensor networks.

Motivation : S-MAC Protocol (Algorithm) turns off the nodes to conserve energy with involvement of MAC layer information: cost of turning off nodes is a added latency and more packets loss compared to non-modified adaptive energy efficient protocol. Therefore we have to design a modified adaptive energy-efficient MAC protocol to find a trade-off between energy conservation and data-deliver quality such as low latency, control overhead. An adaptive energy efficient MAC protocol must enable low duty cycle operation in a multi-hop network and common sleep schedule to reduce control overhead and enable traffic adaptive wakeup.

In many sensor network applications, nodes are idle for long time if no sensing event happens. Given the fact that the data rate is very low during this period, it is not necessary to keep nodes listening all the time. Adaptive S-MAC reduces the listen time by putting nodes into periodic sleep state. Each node sleeps for predefined time, and then wakes up and listens to see if any other node wants to talk to it. During sleeping, the node turns off its radio, and sets a timer to awake it later. All nodes are free to choose their own listen/sleep schedules. However, to reduce control overhead, we prefer neighboring nodes to synchronize together. That is, they listen at the same time and go to sleep at the same time. It should be noticed that not all neighboring nodes can synchronize together in a multi-hop network.

If multiple neighbors want to talk to a node at the same time, they will try to send when the node starts listening. In this case, they need to contend for the medium. Among contention protocols, the 802.11 does a very good job on collision avoidance. Adaptive S-MAC follows similar procedures (CSMA/CA), [17] including virtual and physical carrier sense, and the RTS/CTS exchange for the hidden terminal problem.

All senders perform carrier sense before initiating a transmission. If a node fails to get the medium, it goes to sleep and wakes up when the receiver is free and listening again. Broadcast packets are sent without using RTS/CTS. Unicast packets follow the sequence of RTS/CTS/DATA/ACK between the sender and the receiver. After the successful exchange of RTS and CTS, the two nodes will use their normal sleep time for data packet transmission. They do not follow their sleep schedules until they finish the transmission. With the low-duty-cycle operation and the contention mechanism during each listen interval, S-MAC effectively addresses the energy waste due to idle listening and collisions.

Periodic sleeping effectively reduces energy waste on idle listening. In Adaptive S-MAC,[3] nodes coordinate their sleep schedules rather than randomly sleep on their own. This section details the procedures that all nodes follow to set up and maintain their schedules. It also presents a technique to reduce latency due to the periodic sleep on each node.

Schedule updating is accomplished by sending SYNC packet. The SYNC packet is very short, and includes the address of the sender and the time of its next sleep. The next sleep time is relative to the moment that the sender starts transmitting the SYNC packet. When a receiver gets the time from the SYNC packet it subtracts the packet transmission time and use the new value to adjust its timer. In order for a node to receive both SYNC packets and data packets, divide its listen interval into two parts. Each part has a contention window with many time slots for senders to perform carrier sense. For example, if a sender wants to send a SYNC packet, it starts carrier sense when the receiver begins listening. It randomly selects a time slot to finish its carrier sense. If it has not detected any transmission by the end of that time slot, it wins the contention and starts sending its SYNC packet. The same procedure is followed when sending data packets.

5. CONCLUSION

In this paper, we stated the use of overlapped transmission to enhance the spatial re-use and throughput of wireless networks, by taking advantage of a priori knowledge of the interfering packet. The receiver can employ a simplified IC scheme to receive a packet in the presence of interference. This protocol stack solution that deals with MAC layer and Network layer, which minimizes the energy consumption and delay required to transmit packets across the network. And also the 802.11 MAC protocol can be modified to allow for transmissions to be overlapped by taking advantage of noncausal knowledge of interfering signals. The resulting overlapped CSMA (OCSMA) with An Adaptive Energy Efficient MAC Protocol improves spatial reuse and end-to-end throughput in several scenarios and also which minimizes the energy consumption.

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