An Approach to Contention-Free Protocol in Wireless Sensor Networks Using Smart Clusters

Sujith Reddy Bheemireddi
Computer Science
Oklahoma State University
Stillwater, Oklahoma, USA
Sujith.bheemireddi@okstate.edu

Abstract— **This paper is concerned with wireless sensor network applications where the sensor motes are spatially deployed. A new approach is described which tackles contention with existing MAC protocols. The proposed approach uses smart clusters which are formed only around the event detected areas and the cluster heads are selected based on I-counts to minimize the pressure on cluster heads. As synchronizing only the cluster when compared to the whole network (consisting of hundreds of such clusters) is feasible, TDMA is adapted for these clusters. This layer 2 protocol should offer significant improvements with respect to packet loss and improvements in bandwidths across the network.**

Keywords: CSMA, TDMA, mote, sink, mote clusters, RTS/CTS, sensor network, sensor deployment

I. Introduction

Modern wireless sensor networks typically consists of a radio transceiver with an internal antenna or connection to an external antenna, an electronic circuit (for interfacing with the sensors), a microcontroller and an energy source which is usually a battery. The sensor mote is usually very tiny ranging from few inches to centimeters in size. The sensor motes have a microcontroller which is a very small computer in a single integrated chip and a power source which is very limited due to size constraints which make the transmission area of a mote very limited. A mote can gather sensory data (any raw information), process the collected data and can establish connection with other motes in the sensor network. These connections form bridges for the frames to get transported from source to destination (mote-mote, sink-mote and mote-sink communication). To improve the battery life of these sensor motes, sensor motes can be turned off and on using control signals which are sent by cluster heads or a sink.

A. A wireless sensor mote

A typical architecture of a sensor node is given in figure 1.1 which has five basic blocks. A wireless sensor mote may also accommodate additional hardware such as a GPS device, stabilizers etc. The use of such additional devices makes these sensor motes perform some remarkable tasks such as accurately determining the location of an event using a mote with an attached GPS. Sensors are classified into three categories: passive Omni-directional sensors, passive Narrow-beam sensors and active sensors. Modern sensors are capable of renewing their energy (power) from solar sources, temperature differences. Two policies for saving power are usually employed: Dynamic Power Management (DPM) and Dynamic Voltage Scaling (DVS) [1]. A mote's memory capacity is also very minimal mostly employing flash memory due to its low cost and good storage capacity.

These sensor motes as discussed in this paper have very low memory, power and transmission ranges. The transciever, micro controller and memory in a sensor mote transmits/ receives, processes and stores/retrieves data.

Architecture of Sensor Mote

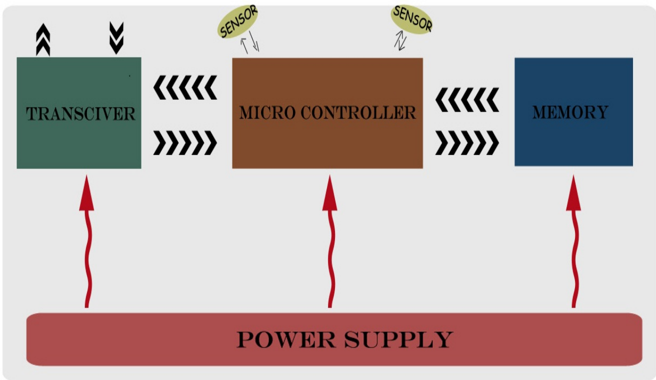

Figure 1.1

A Typical Wireless Sensor Network

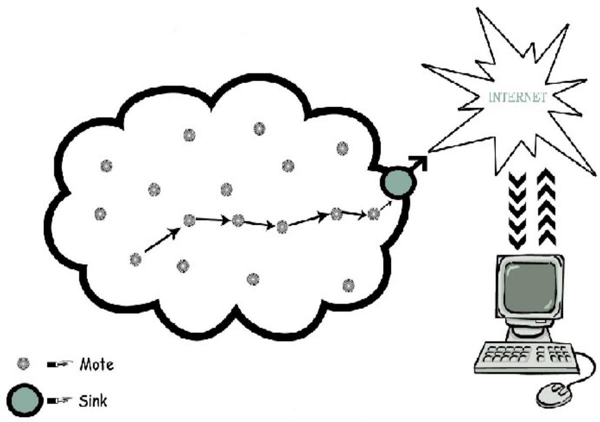

Figure 1.2

B. Architecture of Wireless Sensor Network

A wireless sensor network consists of sensor motes which are deployed in an interested area to do specific tasks such as to monitor an event. As these motes have limited transmission power, they communicate with one another to forward the information to the sink. The sink nodes have special long-range transmission capabilities which are deployed alongside with the sensor nodes to gather sensory raw data collected by individual sensor nodes. Typically the raw data collected by these motes is fused, in stages, and forwarded to the sink nodes that provide the interface to the outside world. Sink nodes are also responsible for training, maintenance and repair operations of sensor networks. A typical wireless sensor network sketch is shown in figure 1.2. Usually a wireless sensor network has a few to several hundreds or even thousands of motes, where each mote is connected to one (or sometimes several) sensors. The topology of the wireless sensor networks can vary from a simple star network to an advanced multi-hop wireless mesh network. The propagation between the hops of the network can be routing or flooding techniques [2][3].

II. Layer 2 Protocol, Contention and CSMA

The operation of 802.11-based wireless LANs are supported by MAC (medium access control) layer which is specified in the IEEE 802.11 standard. The communications between wireless/wired access points and radio network cards (802.11 stations) are maintained and managed by utilizing protocols which coordinate access to a shared radio channel along with the enhancements in the communications over a wireless medium which is all done at the MAC layer. The 802.11 MAC Layer (often viewed as the "brains" of the network) uses 802.11b or 802.11a (802.11 Physical Layer) to perform the tasks of carrier sensing, transmission, and receiving of 802.11 frames [4].

The multiple access protocols are channel access mechanisms (a shared communication medium) provided by the MAC layer. This makes several stations to connect to the same physical medium on a share basis. Some of the examples of shared physical media are ring networks, bus networks, wireless networks and half-duplex point-to-point links. Using a packet mode contention based channel access method the multiple access protocol may detect or avoid data packet collisions or if a circuit switched or channelization based channel access method is used; it reserves resources to establish a logical channel. This mechanism (channel access control) relies on a physical layer multiplex protocol.

The radio frequency signals through which IEEE 802.11g/b wireless nodes communicate with each other is in the ISM (Industrial, Scientific, and Medical) band between 2.4 GHz and 2.5 GHz. To transmit data through frames, transmitters (stations) must first get access to the medium and this medium is a radio channel that these transmitters share. To gain access to this medium, the 802.11 standard defines two forms: PCF (point coordination function) and DCF (distributed coordination function). In the IEEE 802.11 MAC architecture, the DCF is located directly blow the PCF.

Contention occurs when two nearby stations attempt to access the shared communication channel at the same time and the communication tra c is space and time correlated. A contention-free MAC protocol is a protocol which does not allow any collisions.

When we observe human communication, we notice that two parties communicate if they are idle. First the human who wants to talk checks whether the other human is free (idle) for a chat and if not he backs off for a random period of time and rechecks. If he finds that the other person is idle, he initiates the communication. Carrier sense multiple access (CSMA) closely resembles the dynamics of human communication and this is a contention-based MAC scheme.

Figure 2.1 gives the flow of CSMA protocol. If a node wants to transmit frames it checks the medium (common communication channel) whether it is free or not. If the medium is busy (used by some other station), it backs off and rechecks the medium after a random time. If the medium is not busy, the station immeiately gains access over the medium. It now starts to send frames across that medium. In this way, the shared medium is used by the stations employing CSMA where sensing the medium for busyness technique is used to transmit frames. Following so will greatly decrease the amount of collision of frames and thereby increases the bandwidth of the network.

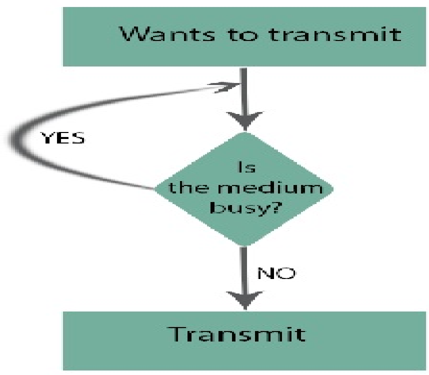

Figure 2.1

There are three basic flavors of a persistent CSMA to handle the scenario when the medium returns to an idle state in a persistent CSMA environment: 1-persistent, P-persistent and O-persistent.

A. The CSMA with CA and CSMA with CD

The CSMA protocol is modified to CSMA/CA and CSMA/CD protocols. Carrier sense multiple access with collision detection (CSMA/CD) improves CSMA's performance by terminating the transmission as soon as a collision is detected. In this way the CSMA/CD enhances CSMA's performance by avoiding second collision on retry. Carrier sense multiple access with collision avoidance (CSMA/CA) is also used to improve the performance of CSMA by attempting to be less "greedy" on the medium. The medium is sensed before a station transmits and if it is busy then the transmission is deferred for a "random" interval which will reduce the probability of collisions on the medium [7].

Figure 2.2 illustrates the flow of CSMA with CD and CSMA with CA.

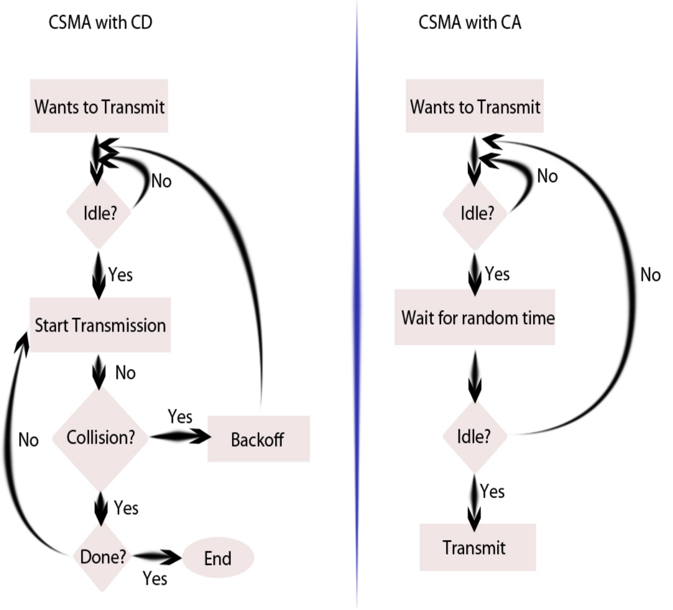

Figure 2.2

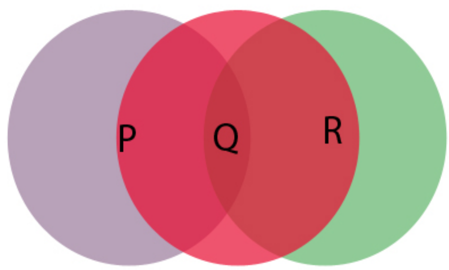

Figure 2.3

The CSMA/CD and CSMA/CA face hidden node problem. Let me illustrate this with an example; Consider this scenario where stations P,Q,R are located in such a way where P can sense Q and R can sense Q but P and R are far apart that they cannot sense each other.

In figure 2.3, if both stations P and R start transmitting to station Q, they will collide with one another. However, the transmitters (Stations P and R) are oblivious to the collision but only station B can see it. As the receiver, it cannot resolve the problem. Only the transmitter can recover from this problem.

B. RTS/CTS

In order to overcome the hidden node problem, IEEE 802.11 uses handshake packets and 802.11 RTS/CTS acknowledgment packets. Employing RTS/CTS may decrease throughput of the network even further and is not a complete solution but adaptive acknowledgments from the base station can help. In RTS/CTS, if a station wants to transmit data, it initiates the process by sending a RTS (Request to Send) frame to the intended destination station. If the destination station is busy transmitting or receiving over the medium, it won't send a CTS (Clear to Send) frame back to the sender. If not, it replies with a CTS frame and any other node receiving the RTS or CTS frame should refrain from sending data for a given time. And the amount of time the node should wait before trying to get access to the medium is included in both the RTS and the CTS frames [6].

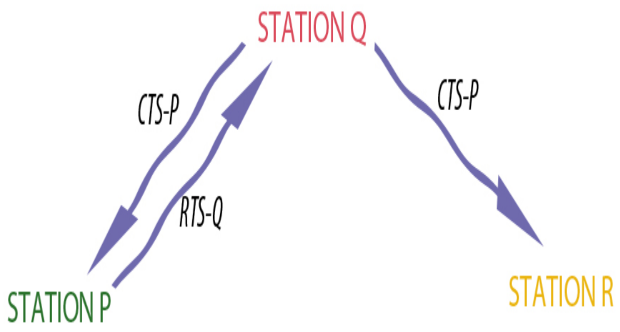

Figure 2.4

In figure 2.4, if station P wants to transmit to station Q, it sends a RTS frame (RTS-Q) to station Q. Station Q replies with CTS frame (CTS-P) and all the stations in its transmission range hear this and they back off and refrain from sending any RTS/CTS packets. Now when station P hears CTS frame from station Q, it accesses the channel and starts transmitting.

TDMA can be used to get rid of primary and secondary conflicts in a network.

- Primary conflict: This conflict occurs when one station transmits and receives in the same time slot or receivs more than one transmission destined to it in the same time slot.

- Secondary conflict: This conflict occurs when an intended receiver of particular transmission is also within the transmission range of another transmission intended for other nodes

In TDMA, the stations are given predetermined slots to gain access to the shared communication channel. If there are 'n' stations, the frame is divided into 'n' slots. One for each station and frames are repeated continuously.

Figure 2.5 illustartes primary and secondary conflicts which may arise in a sensor network.

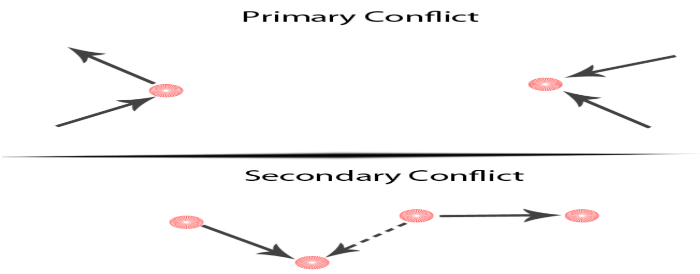

Figure 2.5

III. Scope And Objectives

Wireless sensor networks are sometimes deployed using an airplane because these locations mostly have human challenges in manual deployment and this may be due to geographic reasons or military concerns. Surveillance is the key feature of WSN, i.e., if an event has occurred where a WSN is deployed to report such events, there has to be at least one mote covering that region where the event has occurred. As the WSN deployment done from an aerial method, the motes may not be deployed as planned. Therefore dense deployment is done and this is called as spatial deployment to increase the surveillance of the network. Figure 6.1 illustrates the sensor deployment on a random terrain:

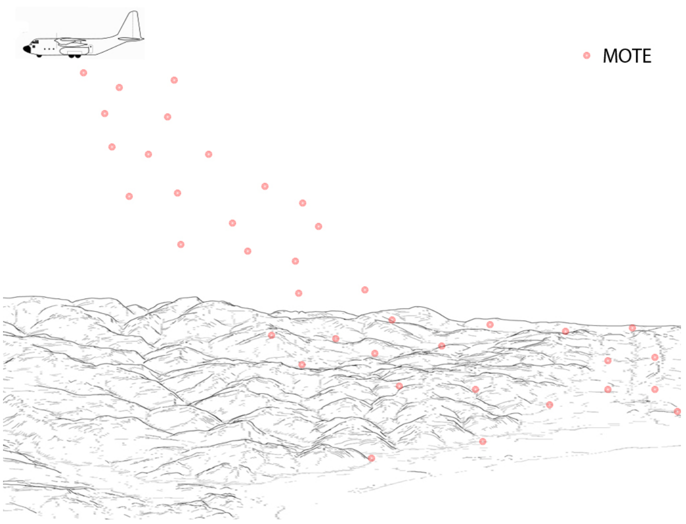

Figure 3.1

The sensor node deployment can be of any fashion such as Gaussian distribution or Poisson distribution. These distributions have many advantages but the main problem is that this planned deployment is very expensive and not possible in most of the cases due to geographic or military issues. Hence, random deployment is most widely used and due to this randomness many issues arise. Extensive research is being done at various institutions to address the issues caused by this random deployment. One such problem caused due to spatial deployment of sensor motes is contention when the existing MAC protocol is used.

Consider a case where a thousand motes detect an event and start transmitting to sink. The sink suppose needs only 20 signals saying that an event has occurred (This is because the motes can be unreliable and they can send false data. Therefore the sink needs to get more signals from different motes to confirm the event) there would be a thousand signals instead. This not only increases the load over the network but also mote channel access gets prolonged and sometimes the packet itself drops because of an overflow of packet frames at motes. Suppose there were many such groups of thousands of motes where many events occurred; it would be a disaster for the network.

There are protocols employing clusters to systematically forward frames. The cluster head collects frames from its cluster members and then forwards it to the sink in a systematic way. Most of these protocols employed in pre-formation of clusters and the election of cluster head in random. All the control messages and frame forwarding is done by the cluster head which depletes the battery of that cluster head. When it dies out, a new head is selected and so on. A technique has to be made where in the formation of cluster is limited to the region of interest and it should be dynamic. Next, the cluster head concept has to be implemented where each time the same mote should not be preselected and the amount of mote usage as cluster head has to be brought down. The goal of this proposal is for a contention free MAC protocol which employees dynamic clustering and smart election of cluster heads to minimize the load on cluster head.

IV. Details Of The Proposed Approach

The core idea behind our approach is to form a cluster near the event area and the members of this cluster are the motes which detected this event. Instead of each and every mote sending frames to the sink, they send it to the cluster head. Cluster head now forwards them to the sink up to a threshold value and sends control messages to the cluster members to stop the transmission. The cluster is formed only around the event region and the selection of cluster heads is made by selecting the motes which have more event detected motes in its transmission range. Depending on the cost, two or more cluster heads are selected and time slice is given to every cluster member specifying the cluster head of that slot. The frames collected at the cluster head are then forwarded to the sink up to a threshold value and then the head gives control messages to cluster members to stop transmitting. After the intended frames sent to the sink are done, the cluster disassembles. Therefore, sequential and controlled frame rate is forwarded back to the sink from these event-detected motes thereby avoiding contention.

Suppose there are a few hundreds of motes which detected an event; all these motes form a cluster by communicating among themselves. Every mote which detected this event sends an initiation packet (I) to every other mote in its one hop range using RTS/CTS. It is possible that motes which did not sense the event might get the initiation packet as these motes might be in the one hop range of an event detected mote. Such motes will not send any initiation packet to other motes but they might receive an “I” frame. Motes store the count of the initiation frames received and these frames also act as synchronizing agents in the cluster to develop a TDMA among the motes in that cluster later on. Two or three motes with the highest count are selected as cluster heads which are near to the sink. These selected motes have higher count values which mean that more motes in their one hop range have detected the event.

This can be illustrated by considering some examples:

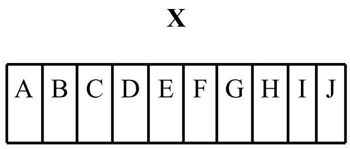

Figure 4.1

Let us consider a case where motes from C to H have detected the event “X” and node 'n' can transmit to n+1, n+2, n-1, n-2 (If A through J are numbered sequentially). That is, motes C and F are in one hop range of D and E but not among themselves. Mote H is in one hop range of I and J. Having this setup, since motes from C to H have detected the event, they will start transmitting the Initiating packet (I) in its one hop range.

Table 4.1 shows the count of those packets received at each node:

MOTE	I-COUNT	FROM
A	1	C
B	2	C,D
C	2	D,E
D	3	C,E,F
E	**4**	C,D,F,G
F	**4**	D,E,G,H
G	3	E,F,H
H	2	F,G
I	2	G,H
J	1	H

Table 4.1

As we can see from the above table, motes E and F have the I-count 4 which is the highest in that table. This count indicates that 4 motes have mote E and F (Those 4 motes in each of these may be different) in their one hop distance. Now, a cluster is formed where motes from A through J as its members and motes E,F as cluster heads.

Let us consider one more example:

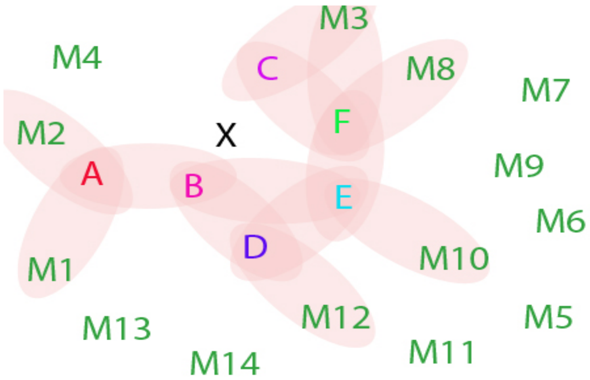

Figure 4.2

Figure 4.2 shows a more real time illustration of WSN scenario where A through F and M1 through M14 are wireless motes. “X” is an event which is sensed by motes A through F. Motes which are at one hop distance are marked using an elliptical pink background. E.g.: A can transmit to B and vice versa in one hop, similarly A and M; B, D, F can transmit to E in one hop etc. When the motes A through F detect the event X, they start sending ‘I’ packets.

Table 4.2 shows the count of those packets received at each node

MOTE	I-COUNT	FROM
A	1	B
B	**3**	A,D,E
C	1	F
D	2	B,E
E	**3**	B,D,F
F	2	C,E
M1	1	A
M2	1	A
M3	2	C,F
M8	1	F
M10	1	E
M12	1	D

Table 4.2

Here, motes B and E are selected as cluster heads because they have the highest I-Count in table.

In this way the cluster heads are elected and the cluster members communicate with these heads. TDMA is used in the cluster to use the shared channel. Instead of using TDMA in the entire network (which is not possible as it is very difficult to synchronize the entire network), cluster synchronization technique is employed.

V. CONCLUSIONS

The sequential and controlled forwarding of detected event by sensor motes is proposed in this paper avoid contention. This sequential and controlled frame traversal is achieved by forming clusters dynamically and the selection of cluster heads is also dynamic. When clusters are formed, cluster heads may not be the same each time.

This lessens the pressure on cluster heads and increases mote life. The proposed contention free protocol increases the bandwidth of the sensor network. Further problems to be considered for this approach include that of security [8].

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