CSMA based Medium Access Control for Wireless Sensor Network

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Abstract—Wireless sensor networks bring many challenges on implementation of Medium Access Control protocols because of the network’s characteristic. In general, medium access control (MAC) protocols for WSN should satisfy the power conservation, mobility management, and failure recovery strategies. Various MAC protocols with different objectives have been proposed for WSN. Most of them are based on either TDMA or CSMA protocols. This report presents a survey of CSMA-MAC for WSN, their advantages as well as disadvantages in comparison with TDMA-MAC protocols.

I. INTRODUCTION

There are many works on designing suitable and efficient MAC protocols for Wireless Sensor Networks. Unlike a typical wired or wireless network, sensor network has a large number of nodes with high flexibility; nodes can easily join or leave the network. Nodes in sensor network are equipped with embedded processor, sensor and radio that make sensor nodes can preprocess data before sending it. In many applications, sensors are deployed randomly in ad-hoc fashion without planning or pre-determined positions. This means that nodes in WSN have the capability of self-organization in a form of multi-hop network.

Due to the features described above, wireless sensor networks have wide range of applications. On the other hand, it required a need for special protocols. Although many protocols and algorithms have been proposed for traditional wireless ad-hoc networks, they are not well suited for the requirements of sensor networks.

MAC protocols have been developed to support nodes to access the communication channels in the network. MAC protocols are considered as the sub-layer on link layer which control how and when a node can access medium to communicate with the other nodes in the network.

Unlike TCP protocol, the end-to-end communication in sensor network is attributed-based [1]. Those factors such as power consumption, scalability and data centric routing must be considered when designing MAC protocols. Either in cellular system or mobile ad-hoc networks, MAC protocols are used to provide system QoS, bandwidth efficiency, but in sensor network, the most important goal of MAC protocols is power conservation, mobility management and fault tolerance capability. As we stated above, the existing MAC protocols designed for wired or wireless network are not suitable for WSN because of the differences in network’s characteristics.

In modern cellular systems, TDMA (Time Division Multiple Access), FDMA (Frequency Division Multiple Access) and CDMA (Code Division Multiple Access) are widely used MAC protocols. They were referred to scheduled protocols, since they have the same basic ideas of avoiding interference by scheduling nodes into sub-channels. Another class of MAC protocols is contention based, in which nodes listening to the channel before transmission (CSMA). If it detects a busy channel, a node can delay access and try later. Recently, CSMA has been studied widely and extendedly.

In scheduled-based MAC protocol, collision almost does not happen since sub-channels do not interfere with each other. But in contention based MAC protocols, collision might be accepted at some levels. Both fixed allocation and random access version of MAC protocol have been proposed for wireless sensor networks [2][5].

In this report, we concentrate on CSMA-MAC protocols for WSN. In Section 2, some requirements when designing MAC protocols for WSN will be recalled while in Section 3, we will compare some proposed protocols. Conclusions will be given in Section 4.

II. MAC ATTRIBUTES AND REQUIREMENTS WHEN DESIGNING CSMA-MAC PROTOCOLS

A. MAC attributes

MAC protocols in WSN are influenced by number of constrains and there are some trade-offs among attributes. It has been emphasized in [1] why the MAC protocols for normal wireless network can not be used in sensor networks.

In infrastructure-based system, networks consist of base stations and the mobile nodes. The base stations form a wired backbone, and mobile node is a single hop away from the nearest base station. The primary goal of MAC protocol is supporting high QoS and using bandwidth efficiently for the network. Because of the base station can have unlimited
power supply and mobile node can be recharged in cellular system, power consumption is only considered as the secondary requirement.

Mobile ad-hoc network (MANET) is closer to the wireless sensor network than the infrastructure-based networks. The nodes in MANET are portable battery-powered devices, they can be replaced by the user and thus power consumption is also the secondary attribute. In this case, MAC protocol has a task of forming the network infrastructure and maintaining the mobility, and a primary goal of provision of high QoS under mobile condition.

In wireless sensor networks, power conservation is the most important attribute. Collision is one factor that leads to waste of energy, hence, all MAC protocols are designed to avoid collision by different ways. The idle listening and unnecessary data sending are also reasons of wasting energy. In many cases, nodes are put into sleeping mode when there is no data transmitting in the network or radio is turned off to save power consumption.

It has been mentioned in Section 1 that, nodes in sensor network can be deployed randomly, thus MAC protocols have to be able to adapt self-organized and changing topologies. Some attributes of MAC in WSN can be placed in the order:
- Collision avoidance
- Energy efficiency
- Scalability and adaptively
- Throughput and latency

B. Requirement when designing CSMA-based MAC protocols for WSN

In most of CSMA schemes (with or without collision detection), packet transmission occur with stochastic distribution, which is very different from sensor network. In sensor network, it is common that traffic is collective structure while existing CSMA protocols mostly used for point-to-point communication traffic (i.e., Ethernet). One of the requirements when designing CSMA protocol for WSN is re-exploring CSMA strategies with a different assumption.

With CSMA, a node wishing to transmit first, listens to the medium to determine if another transmission is in progress. If the medium is in use, the node must wait. If the medium is idle, the node can send data. The collision may happen if two nodes want to transmit at the same time. So the node wishing to transmit listens to the medium obeys the following rules:
1. If the medium is idle, transmit otherwise go to step 2
2. If the medium is busy, continue to listen until the channel is sensed idle

It is obvious that listening is effective if all the nodes can hear from each other. It is not possible in sensor network since the number of nodes are very large. However, nodes are able to listen to each other if radio is turn on, it’s waste of energy. CSMA protocols for sensor network must reduce the length of carrier sensing and have the opportunity to turn off radio.

In the back-off CSMA mechanism, a node transmits with the probability p if the medium is idle and with probability \((1-p)\) to back-off and restart carrier sense. In sensor networks, traffic is superposition of different periodic stream [5] therefore; back-off should not just retrain a node from sending for back-off period.

III. REVIEWING PROPOSED PROTOCOLS

A. Combine CSMA and adaptive rate control scheme [5]

Woo and Culler proposed a MAC protocol for wireless sensor networks which combines CSMA and an adaptive rate control mechanism. In this protocol, a random delay prior is optionally added to listening to avoid repeated collision so that the listening period can be random or constant. The back-off time is used as “phase shift”. Rate control mechanism presented in the paper [5] is very simple. A node in the sensor network attempts to inject a packet. If the packet is successfully injected, it means that the transmitting rate can be increased. If the injection of the packet is failed, the rate has to be decreased. By that way, each node in the network can dynamically adjust its original rate of injecting packet into the network.

It has been concluded in this protocol that constant listening period is energy efficient and random delay provides robustness again repeated collision. Fixed window and exponential decrease back-off scheme were recommended to maintain proportional fairness in the network. The proposed adaptive rate control (ARC) mechanism uses a linear increase and multiplicative decrease approach to control the transmission rate of application. While linear increase brings more aggressive channel competition, the multiplicative decrease controls the transmission failure. This mechanism adapts the rate of transmission of both original and route-thru traffic without any use of MAC control packet.

The scheme presented in [5] is totally computational, which is much cheaper in energy cost than operations on radio. The amount of computational is acceptable within the sensor network computation capacity.

One more interesting point is ARC also attempts to avoid
hidden node problem in multihop network. The transmission rate is constantly tuned and the phase is also changed so that the aggregate periodic stream of traffic will not collide.

B. Collision minimizing CSMA for WSN [7]

Collision-minimizing CSMA protocol, named CSMA/p*, is nonpersistent carrier sense multiple access (CSMA) with nonuniform probability distribution p* is chosen such that nodes use to randomly select contention slots. The protocol has presented a method to treat special workload condition: event-driven workload. In event-driven workload, many nodes send traffic at time of an event, not all event reports are needed and events occur rarely related the time needed to deliver required event reports. Authors showed that CSMA/p* is optimal in the sense that p* is the unique probability distribution that minimize collisions between contending stations.

Some example of sensor network that can generate event-based traffic patterns:
✓ Room monitoring
✓ Power-saving in ad-hoc networks
✓ Indoor location systems

In those applications, latency, not throughput, is considered as performance-limiting factor. The goal of minimizing the latency of the first few successful transmissions in an event-based traffic patterns has been proposed in [7].

The author made an assumption that the traffic is generated with main characteristics:
✓ An event can trigger a synchronize burst of transmissions from a large number of sensor nodes.
✓ Although a large number of nodes may decide to transmit but the application at the data sink may need only few of them.
✓ The number of sending nodes can change quickly.

The main research question in [7] is: If N sensors simultaneously and independently pick one of K slots at some point in time, what is the probability distribution (named p*) on slot that yields the maximum probability of collision-free transmission?

The solution says that the optimal probability for choosing the first of K slots is
\[
1 - \frac{f_{K-1}(N)}{N - f_{K-1}(N)}
\]

\( f_{K-1}(N) \) presents the feedback effect from (K-1) previous slots.

The paper also compared optimal nonpersistent with persistent CSMA, and discussed possible implementation directions for optimal protocol.

C. Medium Access Control with Coordinated Adaptive Sleeping for WSN (S-MAC)

S-MAC is designed specially for wireless sensor network by Ye et al. [9]. S-MAC is built on contention-based protocols in order to remain the flexibility of contention-based protocols while improve the energy efficiency in multihop network. S-MAC also achieves good scalability and collision avoidance by utilizing a combined scheduling and contention scheme.

S-MAC uses a complete listen/sleep frame after TDMA frame for the sleep/wakeup cycle to allow the node spending most of the time in the sleep mode. In S-MAC protocol, all nodes are free to choose listen/sleep schedules, and share with their neighbor. Nodes schedule transmissions during the listen time of the destination nodes.

The collision avoidance in S-MAC is similar to IEEE

<table>
<thead>
<tr>
<th></th>
<th>Scheduled-based protocols</th>
<th>CSMA-based protocols</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Energy efficiency</td>
<td>Good</td>
<td>Need to improve</td>
</tr>
<tr>
<td>Scalability &amp; adaptivity</td>
<td>Bad</td>
<td>Good</td>
</tr>
<tr>
<td>Multihop communication</td>
<td>Difficult</td>
<td>Easy</td>
</tr>
<tr>
<td>Time synchronization</td>
<td>Require</td>
<td>Not required</td>
</tr>
</tbody>
</table>

Figure 1: CSMA-based protocols vs. Scheduled-based protocols
802.11 DCF. Contention only happens at the receiver’s listen period. S-MAC puts a duration field in each packet to indicate how long it need to keep silent, by this way, it puts the node into sleep mode so that S-MAC can save energy.

However, there are some disadvantages of S-MAC. By using S-MAC the latency can increase. Each message has to wait for one sleep cycle on each hop, so latency which is measured by time for message to travel over several hops increase.

It’s necessary to look at some trade-off of S-MAC, such as energy vs. latency and throughput. S-MAC reduces the energy consumption but increases the latency so the throughput is decrease. It has been shown in [9] that, the overall performance depends on the load of the network. Periodic sleep mode provides better performance in the light traffic load than in the heavy traffic load.

D. IEEE802.11 MAC for dedicated short range communication in intelligent transport system

DSRC (Dedicated Short Range Communication) is short-to-medium-range communication service that used in both vehicle-to-roadside (v2r) and vehicle-to-vehicle (v2v) environment. There is strong requirement of designing a suitable MAC and network layer techniques to support DSRC environment.

Two keys scenarios in DSRC applications were described in [10]: a distributed mobile multihop (I) network and a centralized mobile single-hop network (II). Scenario I corresponds to peer-to-peer communication between vehicles while scenario II corresponds to vehicles to roadside communication. The necessary requirements of designing MAC protocol for DSRC environments should focus on: multihop and high-mobility environments.

Existing IEEE 802.11 has some limitations in DSRC environments. In 802.11 protocols, the fundamental mechanism for media access is the distributed coordination function (DCF). DCF is used to support ad hoc network without the need for any infrastructure. Another MAC protocols that used in the network infrastructure based (like media access points) is centralized MAC protocol with point coordinator function (PCF). PCF can be used to archive collision-free time-bounded medium access.

A main problem with 802.11 DCF in multihop network is “blocking” when a node is hidden. In DSRC environments, especially with vehicle to roadside (v2r) communication, when the vehicles move very fast and passing by the roadside unit, there is a requirement of very high downloaded rate in a short time. Therefore, an efficient protocol with low overhead is preferred in such conditions.

J. Zhu and S. Roy have summarized the progress up to date concerning the modeling and analysis of 802.11 MAC in the key areas: DCF modeling, achieving fairness, quality of service, and high-efficiency data transmission. The main conclusions from the article are:

✓ We should design an enhanced MAC layer from 802.11 standards with open interfaces to integrate new solutions. An example is adjusting the contention window (CW) dynamically to meet predefined requirement such as: maximum saturation, throughput, bounded delay, fairness…

✓ The effect of high mobility in ad hoc network is important factor when designing MAC protocol for DSRC environments.

IV. COMPARISION CSMA-MAC & TDMA-MAC

As mention in Section I, CSMA based protocols do not divide the common channel into sub-channel or pre-allocate the channel for individual node in the network. Instead, all nodes share the common channel and it is allocated on demand.

First, we look at the advantages of CSMA based protocols compared with scheduled based protocols. It is obvious that, with CSMA protocol we do not need to schedule in advance, it is more dynamical and flexible to change. CSMA protocols allocate resource on-demand, if some nodes in the network have more traffic load than other nodes or so some regions have higher density than the others do, CSMA protocols are easier to redistribute the network resource. On the other hand, we can say that CSMA protocols are more scalable than schedule protocols, especially when the network topologies change. There is no requirement to form communication clusters and peer-to-peer communication is supported directly. CSMA protocols do not need the time synchronization as in TDMA protocol.

However, CSMA based protocols have some disadvantages compared to schedule based protocols. The major disadvantage is its inefficient usage of energy. Nodes have to turn-on during listening mode, it waste energy. There is still collision in some levels.

V. SUMMARY

The paper reviews CSMA-based MAC protocol for wireless sensor networks. MAC protocols for WSN have to be able to save the power consumption, manage the mobility, self-organization, and failure recovery strategies. Both schedule based and CSMA based MAC protocols using in wireless sensor network have advantages and drawbacks. It depends on applications we can choose the suitable protocols. The combination of these two protocols
is an efficient way of implementing special MAC protocol for WSN, namely **hybrid protocols**.

However, there are still many challenges in designing MAC protocols for WSN. The key challenges remains, such as to provide predictable delay, guaranteed network’s throughput and at the same time reduce the overhead packets to minimize the energy consumption.

**REFERENCES**


