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An Adaptive Mobility-Aware MAC Protocol for Sensor Networks (MS-MAC)

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***Abstract*—Most of the MAC protocols proposed for wireless sensor networks assume sensors to be stationary after deployment, which usually provide very bad network performance in scenarios involving mobile sensors. Handling mobility in wireless sensor networks in an energy-efficient way is a new challenge. Techniques developed for other mobile networks, such as mobile phone or mobile adhoc networks can not be applicable, as in these networks energy is not a very critical resource. This paper presents a new adaptive mobility-aware MAC protocol for sensor networks (MS-MAC). The protocol uses any change in received signal level as an indication of mobility and, when necessary, triggers the mobility handling mechanism. By doing this way, the new mobility-aware MAC protocol can work very energy-efficiently when the network is stationary, whereas it can maintain some level of network performance when there are mobile sensors.**

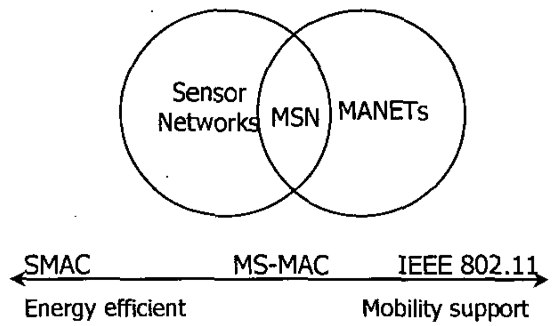

Fig. 1. MS-MAC duty cycle varies with level of mobility

I. Introduction

In wireless sensor networks, maximizing battery lifetime is a very important design criterion, because in many applications changing or recharging battery after deployment is normally not economical or not feasible. To maximize the battery lifetime, protocols at the data link layer usually put sensors in a sleep mode for most of the time, and only let them wake up periodically for data communication. This mode of operation, which trades network Quality of Service (QoS) such as delay, throughput for energy saving, proves to be very effective in stationary networks, where connection formations and break-ups are rare events. However, these protocols, which are customized for stationary networks, may not work well in the mobile scenarios, for example when patients' health conditions are monitored via wearable bio-sensors, workers equipped with sensor device in disaster recovery situation, or soldiers wearing sensors in battle field.

In such mobile sensor applications, each communication node could be very mobile and the level of mobility may vary depending on time of the day. Existing protocols may not create new connection for mobile sensors quickly enough and the network performance may degrade so badly that it may become unworkable. The trade-off of QoS for the energy saving in this case need to be reconsidered. To be effective in both stationary and mobile scenarios, we need protocols that can work efficiently in terms of saving energy for sensors when they are stationary, and at the same time those protocols need to provide acceptable performance level when sensors are mobile. Such protocols need to be mobility-aware and adaptive to mobile sensors' speeds. None of the Medium Access Control (MAC) protocols proposed so far has such capability.

Following are the main contributions of this paper:

- Proposal of a novel mechanism to handle mobility adaptively according to the network mobility status.
- Detailed design of a new mobility-aware MAC protocol to save energy consumption and to provide reasonable QoS in both stationary and mobile scenarios.

II. MS-MAC Protocol

The objective of our new MAC protocol for sensor networks is a protocol that can work energy-efficiently in both stationary scenarios as well as when there are mobile nodes. To achieve this objective, we take S-MAC [4] as a starting point and extend the protocol to support mobile sensors. The mobility-aware MAC protocol for sensor networks (MS-MAC) would work similar to S-MAC to conserve energy when nodes are stationary. At the other extreme, this medium access scheme may also switch to work similarly to IEEE802.11 [8] for a very mobile adhoc scenario. Figure 1 shows the relation between our MS-MAC protocol and SMAC as well as IEEE 802.11.

S-MAC is basically a CSMA/CA MAC protocol, based on IEEE 802.11. SMAC introduces periodic coordinated sleep/wakeup duty cycles (Figure 2), thus extending the battery lifetime for sensor nodes. To maintain synchronization, for every a predefined number (ten) of cycles, each node broadcasts its schedule in a SYNC message, so that its neighbors can update that information in their schedule tables. To avoid two neighbor nodes never see each other (for example, due to

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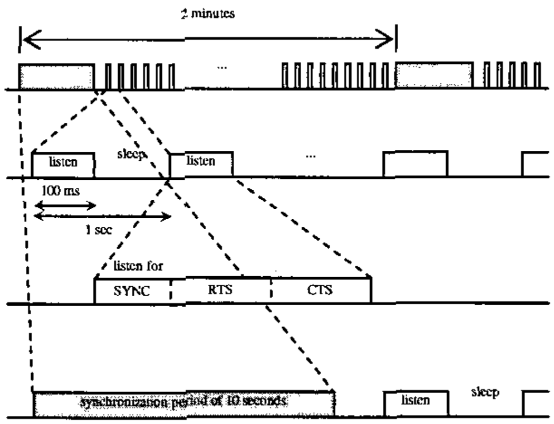

Fig. 2. S-MAC listening, sleeping, resynchronization cycle

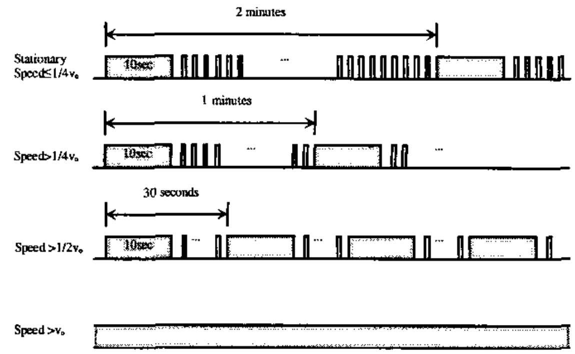

Fig. 3. Frequency of synchronization period in MS-MAC depends on mobile speed

SYNC packet corruption, interference, or because the medium keep busy and SYNC packets can not be sent in time), each node periodically follows the neighbor discovery scheme. For this scheme, the synchronization period (10 seconds) is repeated every 2 minutes. SMAC does not require all nodes in the entire network, but only in each virtual cluster to synchronize. Border nodes between virtual clusters need to follow more than one schedules. The reader is encouraged to read [4] for details.

The SMAC protocol works well when the network is mainly stationary, in which the connection formations and brake-ups are not frequent. If a mobile node wants to set up a new connection with a new node in a different cluster, it has to wait for a new synchronization period (which is 10 seconds every 2 minutes), to be able to detect the SYNC message from the new node. During this connection setup time, the mobile node is disconnected from the rest of the network. This waiting period of up to 2 minutes could be far too long for some time critical applications.

To expedite connection setups, we have introduced a new mechanism in MS-MAC to handle mobility based on actual mobility status of nodes. Each node discovers the presence of mobility within its neighborhood based on the received signal levels of periodical SYNC messages from its neighbors. If there is a change in a signal received from a neighbor, it presumes that the neighbor or it-self are moving. The level of change in the received signals also predicts the level of the mobile's speed. Instead of storing only information on the schedule of the sender node as for SMAC, the SYNC message in MS-MAC also includes information on the estimated speed of its mobile neighbor or mobility information. If there is more than one mobile neighbor, then the SYNC message only includes the maximum estimated speed among all neighbors. This mobility information is used by neighbors to create an active zone around a mobile node when it moves from one cluster to another cluster, so that the mobile node can expedite connection setup with new neighbors before it loses all its neighbors. In the active zone, nodes run the synchronization periods more often resulting in higher energy consumption, but the time it takes to create new connections is lower.

The reason behind the formation of active zone based on mobile speed is that the faster the mobile sensor moves, the less time it takes for it to cross the border between virtual clusters. Getting into a new virtual cluster without knowing the new schedule is a disastrous situation for the mobile sensor as it has to wait for long time for the next synchronization period (by default it is 2 minutes) during which the mobile is disconnected from the entire network. Whereas connection set up among nodes in the same virtual cluster is only 10 second which is the standard interval between periodical SYNC messages. In other words, active zones are only required when there are mobile nodes crossing from one cluster to the other.

To create active zones this way, the mobility information in the SYNC message is set to be empty when a node does not discover any change in received signal levels from neighbors or when the node is not a border node. If a border node detects a change of received signal levels, it will add the mobility information in the SYNC message it is about to broadcast. After receiving such SYNC messages with mobility information, its neighbors will expedite the frequency of their synchronization periods according to the speed of the mobile (Figure 3). The physically mobile node itself also receives SYNC messages with mobility information from the border node and it also quickens the synchronization periods, ready for new connections with new neighbors.

This mobility aware mechanism of MS-MAC protocol allows nodes to work efficiently in both stationary and mobile scenarios. Under a stationary scenario or when mobile nodes only move within a single virtual cluster (such as in Figure 4.a where the mobile node is well inside the virtual cluster 1), all nodes work in a very energy efficient mode. No active zone is formed. Similar to SMAC, apart from waking up for a very short time at the beginning of each cycle, each node only stays awake for the synchronization period of 10 seconds every 2 minutes.

When there is a mobile node crossing cluster borders (Figures 4.b, 4.c, 4.d) the mobile node and surrounding nodes form an "active zone" two hops away around the mobile node.

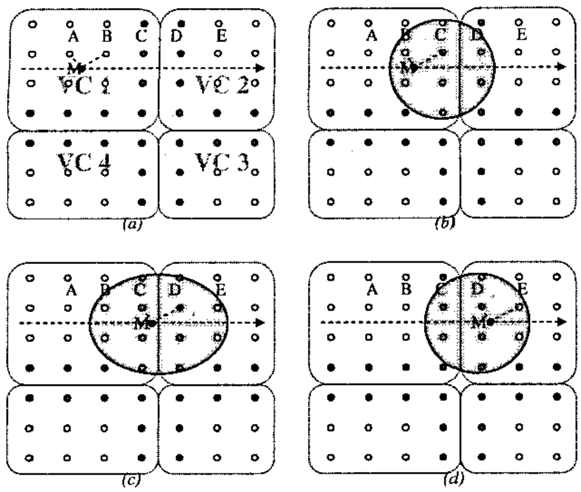

Fig. 4. Active zone is created two hops away around a mobile node which crosses virtual cluster border

In the active zones, nodes stay awake longer. The nodes in the active zones can be awake at all time if the mobile's speed exceeds a threshold v_0 which is application specific parameter. This high duty cycle mode allows nodes to set up connections with new neighbors in a timely basis.

III. Conclusion and Further Research

The new mobility and speed aware MS-MAC protocol aims to work energy-efficiently in both stationary and mobile scenarios, while not giving up totally the performance requirements. To achieve this objective, we introduce a novel mobility handling mechanism at MAC layer. This mechanism is activated and controlled based on the presence of mobile nodes and their speeds. The faster the mobile sensor, the less time it takes to create a new connection with the nearby nodes before it loses all connections. We expect that the protocol performance will outperform that of existing protocols for sensor networks in scenarios involving mobile sensors. Specifically, it would provide much better QoS performance than S-MAC when the network has mobile nodes, whereas it provides comparable energy saving to S-MAC when the network is stationary. We are currently implementing MS-MAC simulation in NS2, and will prototype the protocol using Xbow motes.

Acknowledgment

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