AN ENERGY EFFICIENT MAC PROTOCOL FOR HANETS (SHORT PAPER)

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ABSTRACT

We present a MAC (Medium Access Control) level protocol designed to provide energy efficient inclusion of mobile nodes within an energy-constrained stationary network. Networks of this configuration are defined as Hybrid Ad-Hoc Wireless Sensor Networks (HANETs). Incorporating mobile nodes into HANETs begins with achieving connectivity to the stationary network. To accomplish this, the EAR protocol (Eavesdrop and Register) is presented, which assumes a mobile-centric view of forming, maintaining, and breaking connections, as the mobile nodes are assumed to have fewer constraints on energy supplies compared to the stationary nodes. Using the EAR protocol in HANETs with a dense stationary wireless backbone network provides the ability to maintain a high quality of service in the face of mobility. Furthermore, there is nominal participation by the energy-constrained stationary nodes to maintain network connectivity for mobile nodes.

1. INTRODUCTION

As low-power, low-cost wireless devices become more sophisticated, capabilities of wireless networks will move far beyond those of simple communications. Applications for these new wireless networks are envisioned in areas dealing with high-rate mobile multimedia data transfer, environmental sensing and sampling, homeland security and defense, and health monitoring. The absence of wired links and the support for mobility suggests a variety of networking manifestations, ranging from cellular networks and MANETs to WLANs and Wireless Sensor Networks [1]-[6].

Here, we consider wireless ad hoc networks. The ad hoc nature of these networks arises as the nodes are either (a) required to configure a MAC level link architecture without the aid of a centralized protocol (stationary network), or (b) required to adjust MAC level connectivity in the face of a varying topology (mobile network). Wireless ad hoc networks which provide support for both mobility and stationary sensor nodes are classified as Hybrid Ad-Hoc Wireless Sensor Networks (HANETs). The configuration of the HANETs considered here consists of a wireless stationary network, which is assumed to be densely populated and randomly distributed, and a small subset of wireless mobile nodes. These networks are especially useful in areas where wired connections are impractical (temporary networks) or where the terrain is inhospitable (battleground). In such cases, it may not be possible to replace energy reserves on these sensor nodes, suggesting that network lifetime will be limited. Thus, to prolong the lifetime of the sensor networks, energy is considered to be a prime resource at the stationary sensor nodes.

When mobile nodes are introduced into the stationary network maintaining connectivity to the network will increase the drain of energy reserves at the stationary nodes. As the mobile nodes may be able to return to an energy reservoir to replenish reserves, or to replace battery packs, it can be assumed that they do not share the same constraints as their stationary counterparts. Furthermore, as the entire network is possibly engaged in its own sensing tasks and network operations, the relatively few mobile nodes must operate protocols transparently to the protocols governing the operation of the stationary network. This suggests the need for novel protocol development to control the MAC level interaction between mobile nodes and the stationary network.

Section 2 describes the MAC level goals with networks supporting mobility. Section 3 introduces the EAR protocol, and provides algorithmic attributes. Section 4 gives simulation results, with Section 5 concluding the paper.

2. MAC GOALS

Here, we will focus on the MAC (medium access control) protocols associated with mobile nodes along with the corresponding signaling and resource allocation required to form, maintain, and sever connections to the stationary network. The development of these protocols must take into account various issues which are common to all MAC level protocol designs. In particular, these design issues fall into the categories of Quality of Service (QoS), resource costs, and distributive functionality. The methods by which a given network configuration supports MAC level connections for their mobile nodes, therefore, are dictated by the requirements of the overall network. It is conceivable that various networks will incorporate vastly

different protocols to support mobile nodes based on the connectivity goals and available resources.

The manifestation of mobility in HANETs is significantly different than that of MANETs and Cellular networks. HANETs are comprised primarily of stationary nodes, the set of which forms a self-organized network prior to mobile node introduction. Using protocols developed for MANETs and cellular networks may be sub-optimal due to the distinct goals and constraints presented by HANETs.

Similar to MANETs, all nodes in HANETs will utilize the wireless channel, but lack the ability to transmit at large distances. Cellular networks suggest protocols which incorporate mobile and stationary nodes, but using conventional handoff techniques will suggest frequent handshaking, as smaller transmission ranges will imply more frequent cell transitions.

The design goal of developing new MAC level protocols for HANETs is to provide connectivity to the mobile sensors in the face of properties which distinguish these HANETs from more conventional networks which support mobility. In particular, there are far fewer mobile nodes present in the network relative to stationary nodes, and the stationary nodes are considered to have high energy constraints relative to the mobile nodes.

3. EAR: EAVESDROP AND REGISTER

The EAR algorithm (Eavesdrop and Register) allows mobile sensors to maintain connectivity to a wireless stationary sensor network, while preventing extensive energy consumption at the stationary nodes. It accomplishes this by allowing the mobile nodes to remain inconspicuous to, but to continuously monitor, the stationary network, initiating handshaking procedures only when desired. Before the algorithm is presented, we examine the assumptions regarding the stationary network.

The stationary sensors are randomly distributed, perhaps with no ability to determine location and proximity to other nodes. These nodes have limited battery supplies which we assume are not replenished when consumed. The stationary sensors are operating a slotted TDMA-type frame structure, with synchronization taking place on a link to link basis. At some point during its frame structure, the stationary node enters a "searching" phase, which consists of a polling signal which is used to invite other stationary nodes into the network (assumed to be at a known frequency), followed by a set of slots within which another stationary node may respond.

To allow the mobile MAC protocol to operate transparently to that of the stationary network, we propose that the mobile nodes use the features of the existing MAC protocol. In particular, to avoid specialized pilot signals, or polling, the mobile sensors can simply listen for these "searching" messages, which act as a trigger for the EAR protocol.

The mobile node will have the ability to maintain a registry, which will contain information regarding surrounding nodes. This information can be inferred from the stationary node's regularly transmitted pilot signal. Upon eavesdropping this pilot signal, the mobile node can register the stationary node as a neighbor, with the EAR protocol dictating connection formation depending on received signal quality. The stationary node, on the other hand, will only be responsible for receiving invitation or disconnection messages from the mobile node.

We assume that the mobile sensors are able to control their radios via the MAC protocol. In particular, during any slot, the radio may be switched to receiving mode, transmitting mode, or simply powered off. The EAR protocol assigns a status to every slot within the frame structure, consisting of the power status, corresponding stationary node ID, and communications frequency (or hopping pattern).

The EAR protocol employs a three message scheme. If the pilot signal associated with the stationary MAC protocol is also assumed as a message, though, four messages are used. These are as follows [7]:

Broadcast Invitation: The stationary node invites other nodes to join.

Mobile Invite: The mobile node responds to the BI to request a connection.

Mobile Response: The stationary node accepts, or declines, the MI request.

Mobile Disconnect: The mobile node informs the stationary node of a disconnection; no response is needed.

A. Algorithmic Details

The EAR protocol continually operates in three phases, a registration phase, a connection phase, and a disconnection phase [7].

Registration: Upon reception of the BI message, the mobile node will attempt to enter the corresponding node's information into its registry as simply a neighbor. Continuous registration of multiple stationary nodes will allow the mobile node to determine approximate relative proximity to the various stationary nodes.

If a BI message is received from a stationary node which has already been registered, the mobile node will simply update the required information (signal quality, update time) in the registry. Further updates of received signal quality offers the mobile node to employ open loop power control techniques for communicating with stationary nodes.

Connection: The registry contains all the required information for determining connection selection. When a connection is required, the mobile node will simply scan the registry for the best possible connection, determined by crossing a received signal quality threshold.

The desire to form connections arises in one of two fashions. In the first case, the reception of BI messages from simple neighbors may trigger a received SNR to rise

above the connection threshold, resulting in a connection request. In the second case, as a current connection's received SNR drops below the disconnect threshold, the mobile node will be allowed to disconnect from the current connection and form a new one. Note that once connections have been formed, and the mobile is connected to the maximum allowable number of stationary nodes, a new connection request cannot be made until a current connection fails. Fig. 1 depicts a sample mobile activity in the network.

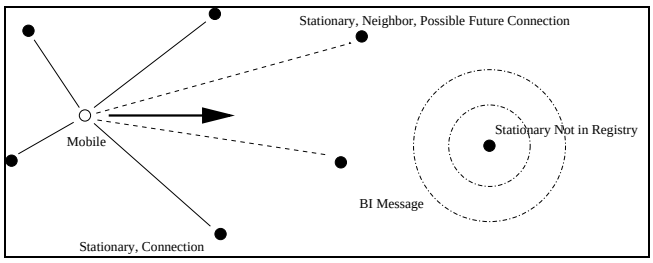

Figure 1. Sample mobile activity.

To request a connection, the mobile node will send an MI message to the stationary node. Along with the connection request, the mobile node will offer the stationary node a selection of possible channels for communications (slot pairs and frequencies). These slots associated with this stationary node will not be offered to another node until dropped as possible communications channels. Upon receipt of the MI message, the stationary node will determine its desire to participate. If a connection is possible, the stationary node registers the mobile node, while selecting a subset of communications channels from the offered set, and responding to the mobile node during the next selected slot with an MR message. At this point, all of the channels not selected by the stationary node are uncommitted, and can be used to invite other nodes.

This MR message represents the only specialized message introduced to the stationary node by the EAR protocol. If a connection is not desired, the stationary node is not required to transmit an MR message, and it simply discards the MI message from the mobile node. The mobile node, therefore, will wait a predetermined time, and then drop the connection possibility.

Disconnection: After forming a connection with a stationary node, the mobile will continue to update the corresponding entry in the registry by receiving data and BI messages. Either of two events will occur causing a disconnection: (a) the received SNR will drop below the disconnect threshold, or (b) the stationary node will "disappear." The disappearance of a node occurs when no data or BI message has been received within a preset time limit, usually due to node failure (depleted energy reserves or malfunction) or deep fades due to shadowing or multipath interference. In such cases, the mobile node will transmit an MD message (at the highest power level to accommodate for disappearing nodes) to inform the stationary node of the failed connection.

B. Algorithmic Properties

The coverage area of each stationary node in the HANET must extend to the neighboring stationary nodes, creating a large overlap region. Thus, the EAR algorithm uses an absolute handoff criterion. Here, each connection is treated separately, as opposed to comparatively for relative schemes. A connection is formed as the signal quality surpasses a connection threshold, and severed as the signal quality descends below the disconnection threshold. Once a connection is formed, it will not be replaced until a disconnection takes place. To ensure reliable communications, the disconnection threshold is usually set higher than the SNR required for communications.

By assuming a high density environment, the EAR protocol is also able to bypass the traditional use of acknowledgement messages (ACKs) by employing a set of timeouts and enabling ACK avoidance. Three types of timeouts are constantly running at the mobile nodes:

Stationary Disappear Timeout: If the stationary node has not sent information warranting a registry update within a preset number of frame lengths, a disconnection occurs.

Mobile Invite Timeout: If a response to a connection request is not received by the stationary node within the allotted time, the mobile node will drop the present request and initiate new connection requests.

Disconnect Timeout: The disconnect timeout is initiated if the signal level falls below the disconnect threshold, lasting a preset number of frame lengths.

4. RESULTS

A simulation testbed for the EAR protocol was implemented in PARSEC [8]. The simulation models the network lifetime, including initial node dispersion, bootup and link formation, routing formation, and mobility support for hundreds of nodes [2].

A network density of 0.4 nodes/m^2 was used for simulations. Each stationary sensor was assumed to transmit at 1 mW, while each mobile node was able to vary its transmit power from 1 to 10 mW. The frame length for the stationary nodes was 8 seconds, consisting of 40 slots per frame. The mobile nodes were allowed to function with frame lengths of 10 slots. At the time of connection request, the mobile node was able to offer 5 slot pairs to the stationary node for communications, of which the stationary node could choose up to 2 sets. During a connected state, it was assumed that the two nodes would transmit data during each of its assigned slots. The mobile node's velocity varied between 0 and 2 m/s.

As the sensor nodes are located near ground level, a distance based power attenuation following a fourth power law was used. To accommodate for a fade margin at the transmitting stationary sensors, the required SNR to register

a BI signal was -5 dB. The SNR threshold to form a connection to a stationary node was varied from 6 to 15 dB, while the allowable drop in signal quality (again measured in SNR) varied from 1 to 5 dB. The mobile node was allowed to monitor the channel during all slots which were not taken up for communications with other sensor nodes.

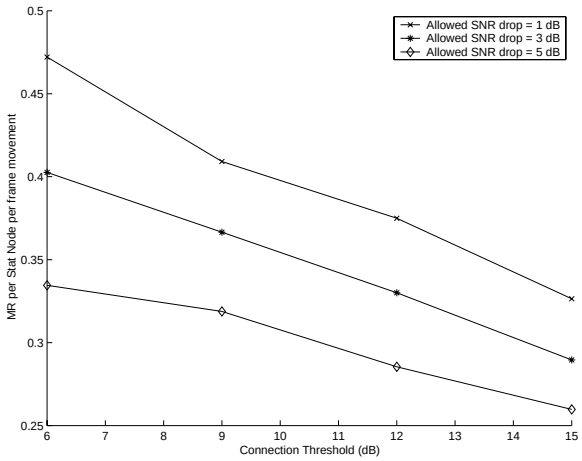

Figure 2. MR message overhead per stationary node per distance moved in one frame length.

Fig. 2 depicts the signaling overhead experienced at the stationary node. The signaling overhead has been normalized to the number of MR messages per distance moved in one frame length. Furthermore, only 20% of the signaling overhead experienced in the network is attributable to the stationary nodes. Fig. 3 gives the throughput available to the mobile node in slot pairs (channels) per stationary frame. For low connection thresholds, it is more likely that the mobile node will form multiple connections, allowing an increase in the number of available channels offered to the mobile node in steady state operations.

5. CONCLUSION

A novel concept of Hybrid Ad-Hoc Wireless Sensor Networks (HANETs) is presented. Due to constraints on energy resources, as well as a large available bandwidth and a low ratio of mobile nodes to stationary nodes, new protocols must be designed for HANETs which provide connection maintenance to mobile nodes.

The EAR protocol, or Eavesdrop and Register, is developed, which suggests a mobile-centric view of MAC level connection maintenance. Essentially, the mobile node utilizes the MAC level features of the stationary protocol, intervening when necessary to form connections. The dense nature of the stationary sensor network suggests that (a) absolute signal levels should be used in the place of relative levels and (b) acknowledgement messages can be avoided without an increase in outage probability.

Results show an ability to maintain high signal quality in the face of mobility, as well as a nominal participation by the energy-constrained stationary nodes to maintain network connectivity for mobile nodes.

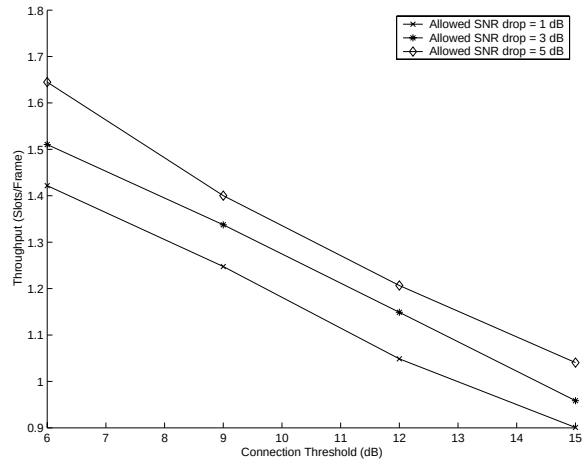

Figure 3. Througput in slots per frame per stationary connection.

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