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Maximizing the Lifetime of Sensor Network using Adaptive Anycast Mac Protocol

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ABSTRACT: Energy constraints in wireless sensor nodes necessitate the design and development of energy-efficient MAC protocols to arbitrate access to the shared communication medium. While there exists a plethora of sensor MAC protocols, these protocols do not individually vary each sensor node's duty-cycle according to local connectivity status to maximize energy savings.

The project proposed A2-MAC - an Adaptive, Anycast MAC protocol for low-powered wireless sensor networks. In this protocol, each node wakes up independently and randomly within a duty-cycle. In addition, it adopts an anycast mechanism so that a node can transmit to any member in its forwarding set. There are 2 key mechanisms in A2-MAC. First, each node adaptively varies its duty-cycle and set of forwarding nodes such that energy consumption can be locally minimized for a given local delay performance objective. Second, nodes cooperatively reduce the duty-cycles required depending on local network connectivity. By allowing nodes to operate with different duty-cycles depending on a local delay constraint and neighborhood connectivity status, A2-MAC is able to extend node lifetime substantially while providing good end-to-end delivery latency. In this project, we are going to evaluate and compare the performance of A2 mac with other mac protocols in terms of network lifetime.

KEYWORDS: Wireless Sensor Networks, Anycast MAC Protocol, Energy Efficiency, Network Lifetime Optimization, Adaptive Communication, Low Power Design, Distributed Networking

I. INTRODUCTION

Advancements in wireless networking and technology have led to the proliferation of tiny computing and sensing devices which are capable of performing collaborative tasks such as tactical surveillance, environmental monitoring, intrusion detection and automation. These network elements are usually densely deployed to maximize sensing coverage and communicate with one another via multi-hop wireless links without centralized control. However, the inherent nature of wireless sensor networks, such as transient physical layer characteristics, intermittent connectivity, node failures and energy constraints, poses challenges to their successful deployment and operation. In particular, the severe energy limitation of sensor nodes has received much focus in the research community. To reduce energy consumption and prolong overall network lifetime, sensor networks are usually duty-cycled - each node wakes up and remains active only for a short period of time, and switches to low-power sleep mode for the rest of the time in order to conserve energy. The Medium Access Control (MAC) layer is responsible for arbitrating access to the shared wireless medium in a fair and efficient manner. Typically, sensor MAC protocols incorporate periodic synchronous or asynchronous wakeup schedules into the medium access control operation, such that nodes need not monitor the channel continuously to receive data packets.

II. RELATED WORK

In the pioneer work on sensor MAC protocols, Ye et al identifies the main sources of energy consumption in any contention-based MAC protocol as: (i) collision; (ii) overhearing; (iii) control packet overhead; and (iv) idle listening. In particular, it is highlighted that nodes in a sensor network without energy awareness will expend most of their energy in idle listening due to the sporadic nature of the network traffic.

Consequently, subsequent works on sensor MAC protocols have always incorporated some form of wakeup scheduling such that nodes do not remain awake throughout the entire network lifetime but wakeup at intervals for communication and to check for channel activity.

Wakeup mechanisms can be broadly classified as: (i) ondemand; (ii) synchronous; and (iii) asynchronous. Sensor MAC protocols that make use of on-demand wakeup mechanisms require out-of-band signaling (using a low power radio) in order to wake up the nodes in time for data reception.

Synchronous wakeup schemes such as S-MAC SMAC/ AL, T-MAC, D-MAC and R-MAC are also known as scheduled rendezvous schemes - nodes wakeup during the same designated time slots for communication. Idle listening is greatly reduced since nodes will wake up and communicate only during the pre-assigned slots. However, tight time synchronization and pre-negotiation of schedules are necessary, which incurs high overheads. In the authors formulate wakeup scheduling as a graph problem. For an arbitrary communication pattern, they assert that the schedule to minimize end-to-end delay is in general NP-hard. Heuristics are presented and used to obtain optimal schedules for the tree and ring topologies. In a multiple-parents, synchronized schedule with multiple ladder schedules similar to D-MAC is presented to reduce latency for communications in data gathering and dissemination traffic patterns. In asynchronous wakeup schemes such as B-MAC and X-MAC the schedules of the sender(s) and the receiver(s) are decoupled, thereby removing the need for any synchronization. Nodes wake up periodically to check for any channel activity - a technique commonly known as LPL (Low Power Listening). If channel activity is detected, the node remains awake to receive the incoming packet; otherwise, the node resumes sleeping. These asynchronous MAC protocols are unicast in nature and use the same duty-cycle for each node. Anycast MAC schemes, whereby a transmitting node sends a packet to any one of the members within a forwarding set, have also been proposed in the context of sensor networks. C-MAC is one such asynchronous MAC protocol. More recently, Kim et al presents opt-MAC, which is shown to perform better than C-MAC, and is an anycast forwarding scheme that combines MAC and routing functions to jointly optimize sleep-wake scheduling (wakeup probability). In opt- MAC, network lifetime is defined as time to first node failure. A key difference between these two protocols (opt-MAC and C-MAC) and A2-MAC is that the latter varies dutycycles on a per-node basis, while the two protocols use the same duty-cycle for all nodes. As a result, A2-MAC can achieve better energy-latency trade-offs. In addition, while opt-MAC can achieve slightly longer times to the first node failure with utilization of end-to-end connectivity information significantly larger proportion of the nodes remain connected in A2-MAC over time, even though only local information is used. In sensor networks where there is often sufficient node redundancy, we believe that the number of connected nodes over time is a more useful network lifetime measure than time to first node failure. Finally, studies the impact of unreliable communication links on data forwarding in duty-cycled networks. With low duty-cycles, link quality measurements performed previously are likely to be outdated. The next-hop is selected from a candidate forwarding set and the metric can be used to minimize the expected delivery ratio, end-to-end delay or energy consumption. One interesting result as claimed by the authors is that opportunistic looping can potentially reduce the overall delay. However, ways to design the wakeup schedule or adapt the duty-cycle are not presented, but assumed to be given inputs to the problem.

III. PROTOCOL DETAILS

In this section, we detail the basic components of A2-MAC, viz. random wakeup schedule, anycast MAC mechanism and interaction with the routing protocol.

A. Basic Mechanism

The wakeup schedule of A2-MAC is based on a slot model. It is important to highlight that it is not necessary to synchronize the slots among different nodes, as the slots are only meaningful locally and the interactions among nodes are based on an asynchronous model. Within each cycle, each node divides its schedule into active (listening) and inactive (sleep) slots. During active slots, nodes wakeup and monitor the channel for activities, analogous to the Low Power Listening (LPL) approach in asynchronous MAC protocols such as BMAC and X-MAC. The remaining slots are inactive, where the node switches to low-powered sleep mode by default. We consider a random wakeup scheduling function, which can be represented as a (v; ®; ¿) design, where v is the total number of slots in each cycle (which should be chosen to achieve a sleep latency constraint); ® · v is the number of active listening slots in each cycle; and ¿ is the duration of each slot in the duty-cycle. Each cycle length is hence given by v:¿ . At the beginning of each cycle, each node randomly selects ® out of v slots to be active in; thus, the probability that a node is active in any slot (awake probability) is ® v . Compared to a synchronous schedule such as S-MAC, the number of active one-hop neighbors during an arbitrary active time slot in A2-MAC is reduced (by a fraction of 1 ¡ ® v), which effectively minimizes collisions and reduces overhearing. Note that in the example given, the slots of each node are unsynchronized with one another. These randomly selected active slots may change during each cycle and the schedule of each node is chosen randomly and independently of other nodes. No communication overhead is required to coordinate and synchronize the wakeup schedules. As we will explain later, this decoupling of schedules between the transmitter and receiver nodes also allows nodes to adapt their duty-cycles with greater ease. As the default active slots of each node are unlikely to overlap, in particular, when the duty-cycle is low, A2-MAC utilizes a probing mechanism to guarantee communication between the transmitter node and its next-hop forwarder (if one exists) within a single cycle period not have any data to send. When a packet arrives at S at slot t3, it switches to active (listening) mode and starts to probe its neighbors using short preambles P in every subsequent slot after the packet arrival, until it receives a preamble acknowledgement AP at slot t6 from its next-hop forwarder f1 that has woken up. Transmission is complete when S transmits the data packet to f1 during slot t7 and receives corresponding data acknowledgement AD in slot t8. The probing for active neighbors using preambles does not incur additional delays or overheads as compared to existing asynchronous MAC protocols, as all such protocols have to transmit preambles for up to the duration of a cycle period to guarantee transmission between any two nodes. When multiple forwarders wake up and detect preamble P at the same time, there may be a collision of AP s. When such a collision occurs, each forwarder will backoff for an interval randomly chosen between 0 and ¿ 2 before retransmitting its AP . As the network duty-cycle (and traffic load) are expected to be low, the probability of collision will be low as well. For example, even when the average node density is 40 (very high node density) and the duty-cycle is 0.01 (® v), the collision probability in a single slot is about 9% 1. When there is only one forwarding node, A2-MAC behaves similarly to X-MAC.

B. Advantages of Combining Anycast with Random Schedules

While anycast has been applied in a number of sensor network protocols , they are mainly used to improve path diversity and provide multiple path routing. In C-MAC, the protocol in fact converges to an “optimal” unicast path over time. We argue that the anycast mechanism should be retained because, when combined with a properly designed (random) schedule, anycast provides advantages such as better robustness to intermittent link connectivity and reduction of end-to-end latency in a duty-cycled MAC.

1) Robustness to Intermittent Link Connectivity:

Due to the transient nature of physical layer effects such as shadowing and fading, communication links between nodes in the network are often time-varying and unpredictable. This may cause the MAC layer to attempt multiple retransmissions across the same temporally-broken link before a link failure is ascertained and an alternative routing path is utilized (if any). Using an anycast mechanism, the node can select its forwarding node dynamically based on prevailing link conditions and application requirements. This achieves load balancing (especially if the next-hop node is an intermediate node for many routes), alleviates the effects of temporary link failures, as well as improves the delay and efficiency of the network. In addition, with a random schedule that distributes the availability of for- warding nodes over time, the anycast mechanism can recover better from fading at the physical layer.

2) Reduction in Latency:

As schedules are asynchronous and randomized, a packet can be transmitted across multiple hops in a single cycle with v time slots, in contrast to scheduled
rendezvous schemes such as S-MAC and R-MAC , whereby active slots are congregated together. Considering the (10, 1, 2ms)-design as shown in Figure , a packet can be transferred from node S to f1 in time slots t5 and t6 (of S), and node f1 to f2 at time slots t6 and t7 (of f1). While the number of transfers performed in each cycle will vary, it is highly likely that there will be a transfer of at least 2 hops in one cycle, resulting in lower end-to-end delay in A2-MAC. Since the active listening slot positions in a cycle length are randomly chosen, the average waiting time (or sleep latency) Ti (measured in slots) of an arbitrary node i before one of its forwarders is awake is dependent on v and ®, computed by:

C. Interaction with Routing Protocol

A2-MAC does not specify a particular routing protocol. Instead, what it needs from a routing protocol are: (1) a set of candidate forwarding nodes; and (2) a metric that indicates the progress that can be made if a particular forwarding (next-hop) node is selected. Such “progress” based routing metrics are very common and examples include hop count. To destination, geographical distance and expected number of transmissions (ETX) . To be concrete, we use the Maximum Forward Progress (MFP) routing metric, which forwards packets based on the geographical locations of the nodes. Each node is assumed to have the location of the sink(s) and its own location, which can be obtained via GPS (Global Positioning System) or existing localization schemes. The preamble transmitted by a node contains both the locations of itself and the sink. This enables each one-hop neighbor to determine its eligibility in forwarding the packet to the destination. Upon receiving the preamble, each neighbor computes its geographical distance to the specified sink. Only neighbors with positive progress (closer to the sink than the transmitting source) are considered eligible forwarders. As no state information is required in MFP, this allows us to study the performance of A2-MAC without routing overheads.

SOFTWARE REQUIREMENTS
NETWORK SIMULATOR VERSION 2

IV. CONCLUSION

The severe energy limitations in sensor nodes accentuates the need to design energy-efficient MAC protocols, typically in the form of duty-cycling, to reduce energy consumption and extend network lifetime. However, duty-cycling inevitably increases the latency incurred during packet transmissions, as transmitters now have to wait for the next-hops to be awake before data communication can commence. In this paper, we propose A2-MAC - an adaptive, anycast-based MAC protocol which utilizes a random wakeup schedule for duty-cycling. The random scheduling adopted in A2-MAC removes the need for any synchronization overheads and allows it to operate asynchronously. A2-MAC makes use of an anycast mechanism to reduce packet delays by allowing a node to select multiple one-hop neighbors as the next-hop destination. A2-MAC is able to dynamically adapt its forwarding set and duty cycle according to network topology and a given per-hop delay or rate of progress. This enables A2-MAC to achieve energy efficiency with low end-to-end delay, as well as better network lifetime measured in terms of number of connected nodes over time. We show through simulations that A2- MAC performs significantly better than existing asynchronous sensor MAC protocols such as X-MAC and opt-mac which is designed to optimize time to first node failure.

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