Performance of location based routing in IEEE 802.15.4a low data rate Wireless Personal Data Networks

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I. Problem overview

The IEEE 802.15.4a standard provides a framework for low data rate communications systems, typically sensor networks, with ranging and positioning capabilities [1]. In this paper an overview of the key aspects of the 802.15.4a Medium Access Control protocol is provided, focusing on network organization, access strategies and ranging procedures at the MAC layer. This overview provides the basis for the analysis of the performance of a location based routing algorithm, that takes into account the overhead required for obtaining position information in 802.15.4a networks.

A. Network organization

The 802.15.4a standard defines two classes of devices: Full-Function Devices (FFD), in which all network functionalities are implemented, and Reduced-Function Devices (RFD), that only support a reduced set of functionalities, e.g. sensor nodes that measure a physical parameter and can execute simple commands. RFD and FFD devices organize themselves in Personal Area Networks (PANs). A PAN is controlled by a PAN coordinator, in charge of setting up and maintaining the PAN. The role of PAN coordinator can only be taken by a FFD device, while RFD devices can only join an existing PAN by communicating with the PAN coordinator. A PAN can adopt either of the two following network organizations:

- *star topology* - Devices can only exchange information with the PAN coordinator;
- *peer-to-peer topology* - FFD devices can communicate directly as long as they are within physical reach, while RFD devices, due to their limitations, can only connect with the PAN coordinator.

The peer-to-peer topology provides higher flexibility, and allows more complex topologies, based on multiple clusters; algorithms for the creation and management of such larger networks are however not part of the standard.

B. Access strategies

Medium access within a PAN is controlled by the PAN coordinator that may choose between either *beacon-enabled* or *nonbeacon-enabled* modality.
In the *beacon-enabled* modality, the PAN coordinator broadcasts a periodic beacon. The period between two consecutive beacons defines a superframe structure divided in 16 slots. The first slot is always occupied by the beacon, while the other slots are used for data communication by means of random access, and form the so-called Contention Access Period (CAP). The beacon contains information related to PAN identification, synchronization, and superframe structure.
The beacon-enabled modality is only adopted when the PAN has a star topology. In this case, two data transfer modes are available:

1) *Transfer from a device to the coordinator* - a device willing to transfer data to the coordinator uses either ALOHA or slotted Carrier Sensing Multiple Access with Collision Avoidance (CSMA-CA) to access the medium.
2) *Transfer from the coordinator to a device* - when the coordinator has data pending for a device, it announces so in the beacon. The interested device selects a free slot and sends a data request to the coordinator, indicating that it is ready to receive the data. When the coordinator receives the data request message, it selects a free slot and sends data using either ALOHA or CSMA-CA.

In order to support low-latency applications, the PAN coordinator can reserve one or more slots for those devices running such applications avoiding thus contention with other devices. Reserved slots are referred to as Guaranteed Time Slots (GTS), and they form the Contention Free Period (CFP) of the superframe.
In the *nonbeacon-enabled* modality there is no explicit synchronization provided by the PAN coordinator. This modality is particularly suited for PANs adopting the peer-to-peer topology, but can be adopted in a star network as well.

C. Ranging support

One of the key innovations of 802.15.4a is the accurate ranging capability, although support for ranging in 802.15.4a-compliant devices will be optional.
Distance estimation between two devices is based on a two

way ranging approach, without the need for a common time reference.This approach an exchange of at least two packets: a device A starts a ranging measurement by sending a ranging packet to a device B at time t_{start}. Device B replies with a second ranging packet, transmitted after a delay ΔT. The packet is received by device A at time t_{stop}. The knowledge of the time interval $t_{stop} - t_{start}$ and of the delay ΔT allows to determine the propagation time t_{flight}. In [2] a similar scheme was proposed for UWB ranging.
The two way ranging procedure involves time intervals measured by two different devices, using different reference clocks. If neither of the devices involved in a ranging estimation is capable of determining the offset between clocks, a protocol-based solution for compensating such offset is adopted. Such solution, based on the concept of Symmetric Double Sided Two-Way Ranging (SDS-TWR) proposed in [3], consists in repeating the packet exchange twice, inverting the role of the two devices in the second exchange. Furthermore, additional packets are required in order to set-up and finish the ranging procedure, since the ranging function must be enabled and disabled in the receiving device and to enable private (that is, secure) ranging. By the end, in the worst case, ranging can thus require up to eight packets to be exchanged between the two devices. Additional packets are further required when the ranging procedure is requested by a third device, in order to send the ranging command to the initiating device, and to collect time measurements from both devices. The significant overhead introduced by ranging in the 802.15.4a standard should thus be taken into account in the design of applications requiring distance information, e.g. positioning algorithms, to be deployed in 802.15.4a networks.

II. Positioning and routing

The complete version of the paper will present an analysis of the performance of a location based routing algorithm based on the Greedy Perimeter Stateless Routing (GPSR) protocol, originally proposed in [4]. The Greedy Perimeter Stateless Routing protocol uses positional information as the key metric in packet forwarding, using a simple ”greedy” forwarding strategy:

1) Each packet is marked by the source terminal with the information about the location of the destination.
2) Each intermediate node forwards the packet to the neighbouring node closest to the destination.

The above strategy by itself does not guarantee that a path between source and destination is always found, as situations may occur in which a terminal is closer to the destination than any of its neighbours. In these situations the protocol switches from a greedy forwarding strategy to a perimeter forwarding one, in which a terminal is allowed to forward the packet to a neighbour which is farther than itself from the destination, in order to solve the stall caused by greedy forwarding. The perimeter forwarding, based on planar graph theory, guarantees that a path between source and destination is always found.
The main advantage of GPSR is in the reduction of the state information in each terminal, if compared to traditional table-driven algorithms. In fact, each node only needs to maintain information about its one hop neighbours locations, which is exchanged by means of periodic beacons broadcasted by each terminal. This means that the amount of routing information is only dependent on the network density (average size of neighbours for each terminal) and not on the network size. It should be noted however that the algorithm only works if all nodes share the same coordinate system, that is if the position of the destination attached by the source in a packet is coherent with the positional information available to the intermediate nodes.
The position information will be obtained by using the Self-Positioning Algorithm (SPA) [5]. The protocol has the goal of providing each node in the network with its own position in a common coordinate system. In absence of external reference points (*anchor nodes*) the nodes are only able to position themselves in a relative coordinate system; in some cases this information is however sufficient for enabling location-based optimizations: this is the case for location-based routing.
The SPA algorithm is organized in two phases. During Phase 1 each node attempts to build a node-centered coordinate system, called Local Coordinate System (LCS) centered on itself. In order to build its own LCS, each node i determines its distance from its neighbours, and shares this information with the neighbours themselves. If the network density is high enough, node i can use this information to define a coordinate system. The coordinate systems independently created by the nodes in Phase 1 are then harmonized during Phase 2, ideally leading to a unique coordinate system all over the network, and enabling thus the use of the GPRS routing protocol.
The performance analysis will determine the impact of location based routing on network lifetime, throughput and delay, taking into account the overhead introduced by both the ranging scheme used in 802.15.4a and the SPA positioning algorithm, used for obtaining and distributing throughout the network the position information required for location-based routing.

Acknowledgements

This work was partially supported by the European Union within the Integrated Project n. 506897 - PULSERS.

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