A High Configurable Protocol for Indoor Localization Systems

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Abstract— **We present a novel protocol for IEEE 802.15.4 beacon-less sensor networks, which provides support to RSSI-based localization algorithms to estimate the position of mobile nodes. The proposed protocol is designed to allow the application to change the mobile node operation mode on demand. In this way it is possible to manage the trade-off between energy consumption and achieved position accuracy. First results related to the parameterization of the protocol and the expected mobile node energy consumption are presented.**

Keywords—Battery; RSSI; Localization; WSN; Sensor Node

I. INTRODUCTION

In Wireless Sensor Network (WSNs) the position information is used not only by clustering techniques or routing algorithms, but also by many attractive indoor context-based applications such as navigation systems, access control and monitoring.

Some localization algorithms require inter-node measurements, like the Received Signal Strength Indicator (RSSI), for determining the node position. Usually these measurements are referenced to nodes with known positions called anchors (ANs).

The RSSI measurements have a great dispersion and are influenced by shadowing, multipath effect and the environmental conditions. These problems degrade the achieved position accuracy. The main advantage of the RSSI-based localization algorithms is that the RSSI does not demand additional hardware. Usually, the low-power transceivers provide this information, which can be easily read by the microcontroller (µC).

In a localization system, there is an inherent trade-off between energy consumption and performance. For instance, several RSSI samples from many ANs can improve the position accuracy [1]. Unfortunately, the excessive signaling of the localization process degrades the lifetime of the Mobile Node´s (MN) battery.

We present a high configurable localization protocol, which allows the MN to adapt its operation mode according to the necessities of the user like the position accuracy, position estimation updating and energy consumption. In this way, it is possible to strategically manage the abovementioned tradeoff. In this paper, we focus on the analysis of the MN´s energy consumption in its different operation modes.

II. PROTOCOL DESCRIPTION

Our reference sensor network consists of IEEE 802.15.4 sensor nodes. The ANs are interconnected forming a tree topology, where a node, which acts as coordinator, is the first level in the hierarchical structure. It is connected to a PC that can collect information and configure the network. The ANs are fixed and have the possibility to be powered externally. In contrast, the MN has a battery and therefore our main goal is to maximize its lifetime. In the network, each MN has a specific AN as reference. This node is called "selected AN" and is in charge of the MN´s communication. In some cases, the selected AN calculates the MN´s position.

The proposed protocol divides the MN´s tasks into different phases within the time domain. A determined set of phases forms a period, which is cyclically executed by all nodes in the network. Each node in the network knows the duration of the phases and the period. By using a synchronization protocol the nodes initiate the phases at the same time. In the next section we describe the synchronization process in detail.

In these phases, different tasks will be carried out depending on the MN´s operation mode. Principally, there are four different kinds of phases. In phase SYNC, the ANs broadcast packets containing information about the synchronization of the network as well as the coordinates of the ANs. These packets can be used by the MN to take RSSI measurements and know when the next phase starts. The phase REPORT is executed to allow the MN to inform about its measurements/state and receive information from the ANs. The phase VIP is reserved for the MNs that require consuming as little energy as possible. Here, such MNs broadcast short packets and the ANs take RSSI measurements. Finally, in the phase COM_SINK the communication between the ANs and the central computer is carried out. In this phase the MNs sleep consuming very little energy.

One period, of duration T, consists of three SYNC phases, two COM_SINK phases, one REPORT phase and one VIP phase, see Fig. 1.

By using our protocol there are many possible operation modes for the MN. In this paper we describe the most relevant types, which define the different tasks executed in the phases of a period:

Mode 1: In this configuration the MN listens during one or more SYNC phases to take RSSI measurements from the ANs. Between SYNC phases the MN sleeps to save energy.
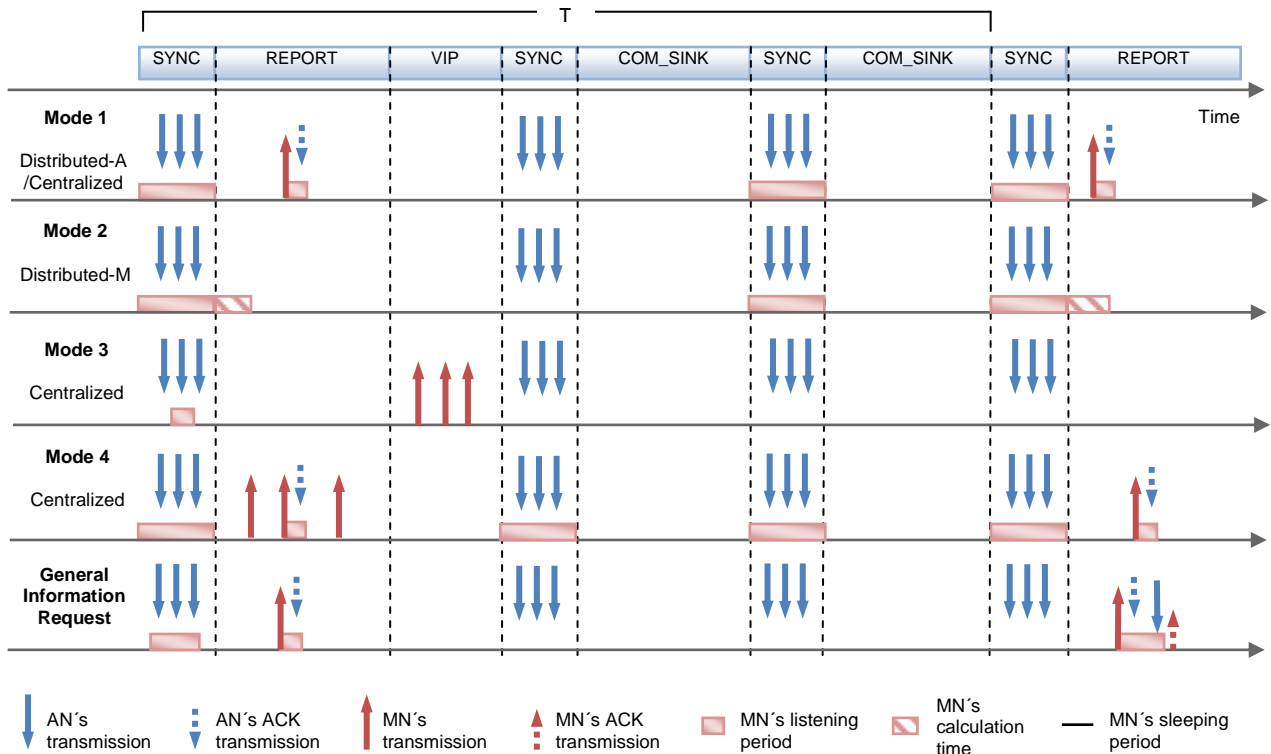
Figure 1. Timing of the Mobile Node in the different operation modes

After taking a certain number of RSSI samples, the MN informs about its measurements in phase REPORT. For this purpose the MN assigns a selected AN (e.g. according to the strongest registered RSSI), waits a random delay and wakes up to transmit its measurements to the selected AN. It confirms the reception by transmitting an ACK to the MN. After this process the MN sleeps.

The random delay is to distribute the transmissions across the phase. This minimizes the hidden terminal problem and avoids large backoff periods (CSMA) when several MNs want to transmit at the same time.

In phase COM_SINK, the AN, which has received the MN´s RSSI measurements, can send this information to the sink to estimate the MN´s position (centralized calculation). Here, a central computer with high processing power can execute complex localization algorithms. Another option is that the AN calculates the position for the MN (distributed-A calculation [1]) avoiding the traffic to the sink.

Mode 2: The MN wakes up in the SYNC phases to synchronize and take RSSI measurements. Due to the fact that the packet also contains information of the AN´s positions, the MN calculates its position by executing a low power localization algorithm (distributed-M calculation).

It is not necessary that the MN listens in all SYNC phases. It depends on the number of RSSI samples required by the application.

Mode 3: This mode of operation was designed for applications where a centralized calculation is required and the MN´s energy consumption has to be very low. Here, the MN broadcasts packets randomly over time in phase VIP. Between the transmissions the MN sleeps. The

ANs take RSSI measurements and send this information to the sink during phase COM_SINK.

Only when the MN needs to synchronize, it listens during a short time in phase SYNC to receive just one packet. The repetition frequency of this process depends on the possible MN´s clock drift.

The main disadvantage of this mode is that each AN, which has received the MN´s packets, transmits its RSSI measurements to the central computer generating excessive traffic in the network.

Mode 4: This configuration is a combination of the other modes and is proposed for applications that require high accuracy and for when the MN´s consumption is not critical.

The MN listens in the SYNC phases and selects an AN according to the strongest registered RSSI value. In the phase REPORT, it informs about its measurements to the selected AN. Additionally, the MN broadcasts short packets in this phase. The ANs take the corresponding RSSI measurements. Consequently, the ANs transmit their measurements to the sink in phase COM_SINK. The selected AN also sends the report received from the MN.

General information request: This sequence is executed by all MNs when they want to receive information from the sink/ANs, like the calculated position or new instructions.

Firstly, the MN listens during the SYNC phase. Thus, it obtains the synchronization information and selects an AN regarding the registered RSSI measurements. In phase REPORT the MN sends a packet with its measurements to the selected AN. In the same packet, the MN indicates that it will ask for a certain data from the network in the next period. If the AN does not have the required data, it asks the central computer in phase COM_SINK.

In the next period, during phase REPORT, the MN sends a request packet to the above selected AN. The selected AN confirms its reception by transmitting an ACK. The MN listens during a certain time waiting for the required data from the AN. When the data is received the MN transmits an ACK. In case the AN does not have any data for the MN, the AN transmits one packet to inform about it. This allows the MN to avoid large idle listening periods.

II. ANALYSIS

The standard IEEE 802.15.4 [4] proposes CSMA in the MAC layer to decrease the packet collisions. The main drawback of the CSMA process is that the transceiver consumes extra energy when it waits a random time (backoff delay) and checks if the channel is idle or busy during the Clear Channel Assessment (CCA). If the channel is free the MN can transmit, if not, it has to repeat the mentioned process. After a certain number of unsuccessful attempts the MAC layer notifies the application layer by sending a Channel Access Failure (CAF). The application layer can discard the packet or try a retransmission.

In [1], an energy model was proposed for 802.15.4 nodes. It takes the influence of the random backoff delay and the CCA into account. We use this model to compare the MN´s energy consumption in the different operation modes. The sensor node RCB230 [3] was taken as reference in our analysis. It consumes 66.72mW in the transmission mode (at 3.2dBm), 64.96mW during the listening period and 43.42mW in the backoff process. Further information about the energy consumption in other operation modes can be found in [1]. The default configuration of the MAC layer proposed in the standard is used in the analysis.

A. Phase SYNC

In this phase the ANs randomly broadcast packets. They are used by the MN to obtain RSSI measurements, and for the network synchronization.

The broadcasted packets contain information of the AN´s position, the identification number (ID) of the next phase and the remaining time to the next phase. The nodes have the capability to create timestamps with a resolution of μs. Thus, it is possible that a node knows when the next phase starts, enabling the synchronization. In our network the coordinator is the time reference and initializes the synchronization propagation. The ANs start broadcasting packets only when they are synchronized. Between transmissions the AN listens to the new synchronization packets from its parent (tree topology) and other ANs. In this way it is possible that the ANs are always synchronized. Note that all nodes know the duration of the phases and the entire period.

The remaining time to the next phase is calculated by the application level. This information is included in the synchronization packet and sent to the MAC layer for its transmission. Due to the random time of the CSMA process, the packet is not immediately transmitted. This random time offset degrades the synchronization performance, because it is unknown by the receivers.

For this reason, during this phase, the ANs configure the MAC to disable its random backoff delay. Thus, it is possible to have a constant time offset between the

moment when the remaining time was calculated and the moment of the transmission. However, in order to minimize collisions a random delay has to be generated in the application level before the CCA detection. Thus, next to this random delay, the remaining time is calculated and, after a constant time offset in the MAC level, transmitted. Under this MAC configuration, in case the channel is busy during the first CCA detection, a CAF is sent to the application level, which tries a retransmission.

By using simulation (OMNET++) we investigate the impact of the maximum random delay Rd in the application level. In this test scenario six ANs are strategically placed (avoiding the hidden terminal problem) and transmit four packets of 0.8 ms. Before a transmission a random uniform distributed delay [0,Rd] is generated. A MN registers the instant of the last packet arrival and the total of received packets. The corresponding average values and confidence levels of 95% are depicted in Fig. 2.

These results are useful for correctly defining the duration of the phase. In the figure we can observe that there is a saturation effect in the curve of the received packets when Rd takes values higher than 20ms. The lost packets are mainly due to the fact that two or more anchor perform CCA and find the channel free at the same time leading to a collision during transmissions.
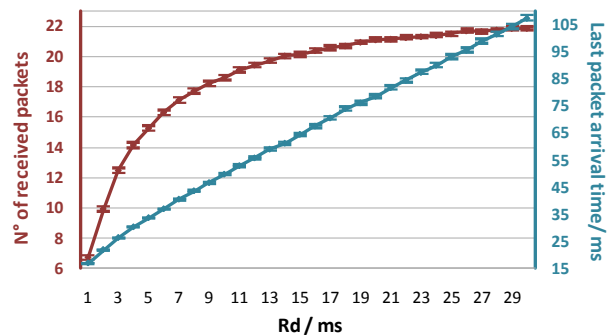

Figure 2. Impact of the maximum random delay before a transmission (Rd) in phase SYNC.

B. Phase VIP

In phase VIP the MNs (in mode 3) randomly broadcast short packets over time. If many MNs transmit packets in this phase, the probability P_f that a node finds the channel free decreases. Thus, the expected backoff delay for one transmission takes higher values. Therefore, the traffic load has to be kept as low as possible in this phase. This minimizes the expected backoff delay in the MNs, whose energy consumptions is critical.

C. Phase REPORT

The unicast transmissions generated in this phase are followed by the reception of an ACK. This allows the nodes to detect packet losses and try a retransmission. In the standard 802.15.4, the energy consumption generated by ACK packets is not excessive, because they are very short (they do not include payload) and the CSMA process is disabled for such transmissions.

III. COMPARISON

In order to describe the behavior of the MN in the different phases we define the following parameters:

- f_report: frequency in the generation of reports, e.g. if the MN transmits a report every four consecutive REPORT phases, then f_report is 0.25.
- f_listen: frequency of listening in the SYNC phase. If f_listen=1 the MN listens in the three phases of one period.
- f_ask: frequency in the generation of request packets during phase REPORT.
- f_broadcast: frequency in the broadcast of x number of packets during phase REPORT (mode 4) or phase VIP (mode 3).

We analytically investigated the energy consumption of the following operation modes (Fig. 3):

A) Mode 1:
- Phase SYNC (f_listen=0.666)
- Phase REPORT (f_report=0.9; f_ask=0.1):

B) Mode 2:
- Phase SYNC (f_listen=0.666)
- Phase REPORT (f_report=0.05; f_ask=0.05)
- The MN calculates its position one time per period. The low-complexity localization algorithm Min-Max [1] is used. We consider that the calculation time is about 0.870 ms (this time was measured in our reference node by generating timestamps before and after the calculation).

C) Mode 3:
- Phase SYNC (f_listen=0.05).
- Phase REPORT (f_report=0.05; f_ask=0.05).
- Phase VIP (f_broadcast=1; x=3).

D) Mode 4:
- Phase SYNC (f_listen=1).
- Phase REPORT (f_report=0.5; f_ask=0.5
  f_broadcast=1; x=5).

In our analysis the phases have the following durations: SYNC=50ms, REPORT=400ms, VIP=100ms and COM_SYNK=400ms. Thus, the duration of one period is 1450ms. There are 40 nodes that share the same channel (10 nodes of each mode). The duration of all transmissions is 1ms except for the MN´s broadcasted packets, whose duration is 0.7ms. The ACK duration is 0.352ms. We assume that each request packet is followed by any AN´s response. To simplify, the hidden terminal problem [2] is not considered in the analysis.

As shown in Fig. 3, the energy consumptions in the mode 1 and mode 2 are very similar when the MNs operate with the same f_listen. The reason is that the
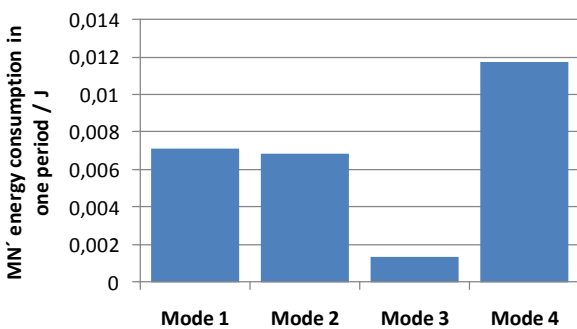

Figure 3. Expected energy consumption in the different MN´s operation modes

TABLE I.
NODE OPERATION MODE

Mode / Calculation	MN´s Energy Consumption	Traffic Generated in the Network	Position Accuracy
1 / Distr.-A	Medium	Low	Low/ Medium
1 / Centralized	Medium	High	High
2 / Distr.-M	Low/Medium	Very Low	Very Low
3 / Centralized	Very Low	Very High	High
4 / Centralized	Very High	Very High	Very High

dominant factor in the consumption of these modes is the listening period during phase SYNC. However, the big advantage of the mode 2 is that it does not generate traffic to the sink, improving the scalability of the network.

As expected, the mode 3 reduces the energy consumption of the MNs by principally limiting the usage of the transceiver to few transmissions during phase VIP.

The operation mode 4 consumes more energy than the other configurations, although more RSSI information can be exploited for the position estimation.

The abovementioned configurations can be strategically selected in terms of the application and the expected QoS. Table 1 provides a qualitative overview of the proposed operation modes and the impact on the network.

In general, the accuracy can be improved if several RSSI measurements are used and if a centralized calculation is carried out. The distributed-A calculation can achieve higher accuracy compared to the distributed-M calculation. This is due to the fact that the ANs have the possibility to store relevant information for the position estimation e.g. fingerprints database, calibration information or part of the building structure.

CONCLUSION

In this paper the design of a flexible protocol in 802.15.4 networks is proposed. It allows the mobile nodes (MNs) to operate in different modes according to the demand and the application. Four operation modes are analyzed: the mode 1 allows an anchor to estimate the MN´s position. In the operation mode 2 the MNs execute a low-complexity algorithm avoiding the generation of extra signaling in the network. The MNs can consume very little energy by using the mode 3. The operation mode 4 should be used when high position accuracy is required. First results regarding the MN´s energy consumption in the different modes are presented and discussed.

REFERENCES

[1] J. Robles, S. Tromer, M. Quiroga and R. Lehnert, "Enabling Low-Power Localization for Mobile Sensor Nodes", International Conference on Indoor Positioning and Indoor Navigation IPIN, Zürich, Switzerland, September 2010.

[2] H. Karl and A. Willig, Protocols and Architectures for Wireless Sensor Networks", Wiley, 2005.

[3] Datasheet IEEE 802.15.4 node RCB230 V3.2, available at: www.dresden-elektronik.de

[4] IEEE 802.15.4 -2006 standard, available at:
http://standards.ieee.org/getieee802/download/802.15.4-2006.pdf