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Simulation framework for modelling energy consumption in ultra-low duty cycle mobile ad-hoc networks

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Abstract: The article presents a simulation framework designed to support development of ultra-low duty cycle mobile ad-hoc network applications. In particular a railway vehicle monitoring system is considered, that is equipped with devices allowing cargo localization. In addition to GPS and GSM connectivity, a local radio network connection is added allowing aggregation of localization data from multiple nodes into a single node's GSM transmission in order to minimize energy consumption. A simulation model developed for studying network behavior and performance is presented, that allows to directly run the target code inside the simulator, features a sufficient clock drift model as well as detailed energy consumption profiling. The article provides model verification results and discusses it's future application.

Keywords: discrete-event simulation, wireless communication, embedded systems, clock drift, energy efficiency.

1. INTRODUCTION

Mobile Ad Hoc Networks (MANETs) have become an important research topic over the past years. Due to the nature of their application, the nodes of such networks are usually battery powered, thus one of the most important aspect of their operation is energy consumption. Considering mesh networks, several techniques are used to achieve low overall energy consumption and long battery life time, including low power hardware, MAC and routing protocols, but the main strategy is always reducing node activity which leads to a general low-duty cycle operation (Bachir et al. 2010). However two main constraints exist – one is obviously the actual required rate at which the nodes communicate and perform their application tasks and the other is the ability to maintain the required synchronization between the nodes. The second constraint comes from the fact, that in low power radio transceivers, the power consumption during reception is often significant (even comparable to the case of transmission) and some sort of reception and transmission scheduling is required to inhibit unnecessary energy waste. However, the state of synchronism between the nodes depends on the individual clock drift of each node, which in case of ultra-low duty cycle networks becomes a major concern.

The following chapters describe an application that is a "good fit" for low duty cycle MANETs, along with the discussion of problems that need to be addressed. Next, a simulation framework based on OMNeT++ Discrete Event Simulator is presented with the description of a developed simulation model, that allows to emulate the final software application running on an embedded platform, directly inside the simulator. Following is the description of the model verification method and obtained results. Finally possible energy savings are discussed with the description of future work.

2. ULTRA-LOW DUTY CYCLE MANET IN LOGISTICS

Some particularly interesting applications of ultra-low duty cycle mobile ad hoc networks are in the field of logistics. One example is railway transportation, in which the train carriages carrying goods are equipped with GPS locators and report their position through a GSM/GPRS connection. Due to the fact, that cellular network communication yields relatively high power consumption, significant energy savings can be obtained assuming that locators travel in groups (trains). Based on the long term, in field experiments, that included an almost 2 year-long pilot deployment on railway carriages, it was proven that GSM connectivity consumes a significant part of total energy consumed by locator. Due to non-uniform GSM network coverage, the amount of charge required for successful GSM transmission can reach 1.5mAh at 3.3V. This, depending on other features included, may consume 25-50% of the total battery capacity. The locators however can be equipped with a low-power short-range radio interface that allows them to communicate between each other and form an ad-hoc network, which job is to elect a node that will aggregate the information about the location of several neighbors into a single GSM/GPRS transmission, minimizing energy consumption. Such network has additional purpose – it allows to locally communicate with the locator for servicing tasks and to connect external sensors. Due to range performance reasons, the additional radio interface was chosen to be working according to IEEE

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802.15.4g filtered-FSK physical layer (PHY) specification in the 868MHz band (available in European countries). The simplified block diagram of the resulting locator hardware is presented in figure 1.

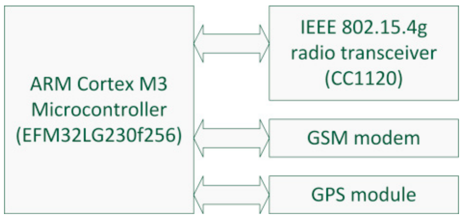

Fig.1. Block diagram of the locator target hardware.

The sufficient location update rate is only once every couple of hours, hence the ultra-low duty cycle operation. The idea is to wake up all the nodes from a deep sleep at a specified absolute time (in ex. every full hour), form an ad-hoc network, elect the best node to transmit the information about the location of networked nodes (cluster head), perform a GPRS transaction and go back to sleep again. This activity is presented in figure 2. Thanks to the GPS interface the nodes can gain access to a precise time, however this also costs energy. Additional savings can be achieved if the nodes are synchronized less frequently than their duty cycle.

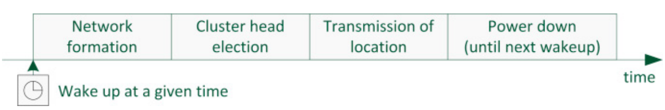

Fig.2. General node activity in time.

The communication protocol for such network must be then optimized to consume as little energy as possible at the stage of network formation, since this is the main network activity the nodes will perform during their life time. In order to gain additional energy savings due to minimized GPS utilization, the protocol should also be capable to deal with clock drift issues that occur in between activity periods.

The development of such communication protocol requires good support from the simulation tools (Khawla et al. 2012). One particular reason for this is that the final application must be proven useful in many distinctive scenarios, including large scale deployments. Considering railroad transportation several special cases need to be considered, such as single long train with multiple carriages, two or more trains passing each other, trains resting in the train station or even carriages left aside in the marshalling yard, that may include several thousand units, to name just a few.

The following chapter discusses the simulation framework that has been crafted to support radio communication protocol development for these kind of applications.

3. SIMULATION FRAMEWORK

Three main objectives of the developed simulation framework are listed below:

- To be able to recompile and run the same application and middleware code in a simulator and on a target hardware platform, without changing a single line of code.
- To be able to test the effectiveness of clock-drift mitigation algorithms inside the simulation, in various scenarios.
- To be able to assess the energy consumption of network nodes in various scenarios, including large scale deployments.

The simulation framework was built based on the OMNeT++ discrete event simulator.

3.1 Portability through hardware abstraction layer

The first objective was fulfilled by using a capable hardware abstraction layer (HAL) that decouples the hardware-independent code from the target platform drivers. By introducing a set of interfaces to the common microcontroller peripherals, such as GPIOs, communication peripherals, timers, memory etc. the embedded firmware code based on HAL is easily portable to different hardware architectures but also can be adapted to run as a simulation. Considering the communication protocol that is focused on energy savings, an event-driven programming style will be favored, thus a discrete event simulator, such as the chosen OMNeT++ is a good match.

Basically two types of events exists, that need to be handled by code:

- events scheduled by the firmware, such as those that handle timeouts, deadlines, periodical tasks etc.
- events signaled by external components, such as the event of receiving a radio packet or finished transmission of an outgoing packet.

The developed hardware abstraction layer provides, among others, the TIM module, that enables an abstract interface to a timer peripheral. This interface provides means to start and stop the timer in a free running mode, get the current timer time value but also to schedule execution of events based on the timer time, by using a common timer peripheral functionality called output-compare. This capability directly corresponds to the scheduling functionality, which is at heart of a discrete event simulator. The application can thus be written in an event-driven programming style, using time-based event scheduling through the TIM module. When the code is executed on a target platform, the realization of the TIM module interface, which in that case is a timer peripheral driver, will manage the event scheduling using the output-compare hardware functionality. When the code is built and executed in the simulator, the TIM interface realization will be a driver relying on the event scheduling capability of the simulator itself.

As with most discrete event simulators, this approach however has a shortcoming of not being able to take into account the event execution time, which for embedded