Emulation of an Active Tag Location Tracking System

Razvan BEURAN [a,b], Junya NAKATA [a,b], Takashi OKADA[b,a], Tetsuya KAWAKAMI[c], Ken-ichi CHINEN [b,a], Yasuo TAN [b,a], Yoichi SHINODA [b,a]
[a] *National Institute of Information and Communications Technology, Japan*
[b] *Japan Advanced Institute of Science and Technology, Japan*
[c] *Matsushita Electric Industrial Co., Ltd., Japan*
razvan@nict.go.jp

Abstract. In this paper we present the emulation of a location tracking system that uses active tags to identify the position of the active tag wearer. Using emulation we were able to carry out live experiments with such active tag applications. Emulation is done using QOMET, a wireless communication emulator, and the active tag processor emulator. Experiments are performed using the experiment-support software RUNE. Emulation is used during the development of the pedestrian localization system so as to perform large-scale experiments easily and in a repeatable manner.

Keywords. active tag, location tracking, emulation

Introduction

Active tags are being researched actively in connection with numerous applications. For example, active tags are used in transport and distribution industries, for factory automation or asset tracking. The communication characteristics of active tags allow for a wide range of applications. One of such applications is that of determining the location of moving objects or people. Location tracking of persons is an important issue related to several events such as disaster situations, public surveillance, etc. For instance, during the evacuation of a school following an earthquake, it is important to be able to determine whether evacuation was completed successfully. If persons are in the disaster perimeter, their location should be identified.

We are developing an emulation system for active tags to make it possible to carry out realistic experiments during the development of active tag applications by running the real active tag firmware within a virtual, emulated environment. Real-world experiments with wireless network systems, and active tags in particular, are difficult to organize and perform when the number of nodes involved is larger than a few devices. Problems such a battery life or undesired interferences often influence experimental results. Through emulation much of the uncertainties and irregularities of large real-world experiments are placed under control. In the same time, using the real active tag firmware in experiments enables us to evaluate exactly the same program that will be deployed on the real active tags; this is a significant advantage compared to simulation.

The active tag emulation experiments are done on StarBED, the large-scale network experiment testbed at the Hokuriku Research Center of the National Institute of Information and Communications Technology (NICT), located in Ishikawa, Japan. To use the testbed for active tag emulation we developed several subsystems, and integrated them with the existing infrastructure. The subsystems were developed on the basis of existing tools that are already used on StarBED, namely the wireless network emulator QOMET [1], and the experiment support software RUNE [2].

To the best of our knowledge this may be the first attempt to emulate active tags so as to perform live experiments in realistic conditions. Active tags were so far mainly studied through simulation, such as the work presented in [3]. We created an experimental platform for active tags in which emulation plays an essential role in:

- Recreating the wireless communication conditions between active tags, so that the information exchanges between them are similar to the reality;
- Emulating in real time the active tag processor, so that the same firmware that is developed for the active tag prototype system can be run and tested.

Matsushita Electric Industrial Co., Ltd. is involved in the development of a pedestrian location tracking system that employs active tags. This system makes use of the data communication and processing features of active tags so as to provide to a central pedestrian localization engine the information needed to automatically calculate the trajectory to date and the current position of the active tag wearer. Using the prototype of the pedestrian localization system, real-world experiments were carried out in March 2007, as reported in [4]. The experiment consisted in the orchestrated movement of 16 pedestrians both in indoor and outdoor environments. The results of this experiment are currently being used as a basis for improving the prototype of the pedestrian location tracking system. One of the conclusions was that it is very difficult to organize a real-world experiment for such applications of active tags. The number of people involved, and the accuracy of their movement following the predefined scenario, are only a few of the issues encountered. Moreover, the pedestrian localization application is intended for use with large groups of people. The active tag emulation system plays an essential role at this point, since it makes it possible to continue the experiments in the development phase with ease.

1. Active Tag Emulation

Using emulation to carry out experiments in a repeatable manner and in a wide-range of conditions implies creating a virtual environment in which the movement, the communication, and the behavior of active tags are all reproduced.

1.1. Emulation System Overview

The active tags used for the pedestrian localization system by Matsushita Electric Industrial Co., Ltd. are based on the AYID32305 tags from Ymatic Corporation [5]. These active tags use as processing unit the PIC16F648A microcontroller made by Microchip [6], which has 4096-word flash memory, 256-byte SRAM and 256-byte EEPROM. Its frequency is configured at 4 MHz for this application. The wireless transceiver of the active tag operates at 303.2 MHz, and the data rate is 4800 bps (Manchester encoding), which results in an effective data rate of 2400 bps. According to Ymatic, the active tags have an error-free communication range of 3-5 m, depending on the antenna used.

The active tag communication protocol was custom designed by Matsushita Electric Industrial Co., Ltd. The prototype system uses a very simple protocol based on time-division multiplexing. Each tag will select at random one of the available communication slots, and advertise its identifier and the current time. The random selection may induce reception errors if two tags choose the same slot. Currently the number of available communication slots for advertisement messages is 9. Message exchanges take place at intervals of about 2 seconds. There are additional communication slots that can be used on demand to transmit location tracking records.

An overview of the system that is currently used for active tag emulation experiments and the development of the pedestrian localization prototype is given in **Figure 1**. RUNE (Real-time Ubiquitous Network Emulation environment) [2] is designed to support emulation of large ubiquitous networks, having features such as: emulate the surrounding environment, support real-time concurrent execution of numerous nodes, provide multi-level emulation layers, etc. RUNE Master and RUNE Manager are modules used in all RUNE-based experiments for controlling the experiment globally and locally, respectively. The active tag module was specifically designed and implemented for this application. This module includes:

- Active Tag Communication and *chanel* spaces, used to calculate and manage the communication conditions between active tags;
- Active Tag Control space, which is powered by the active tag processor (PIC) emulator, and runs the active tag firmware in real time to reproduce the active tag behavior.

The experiment itself is performed using standard PCs (running the FreeBSD operating system) that are part of the StarBED testbed. They are labeled as Execution Units in **Figure 1**.

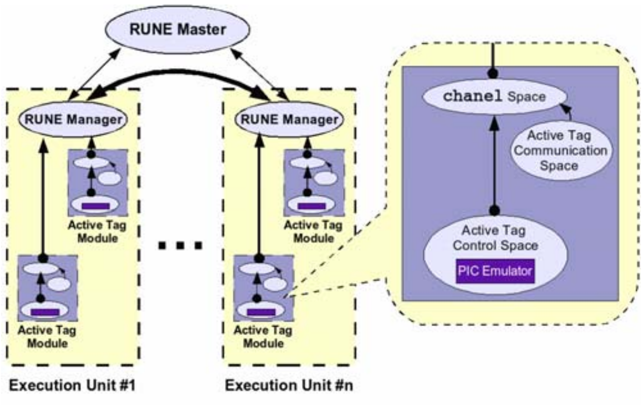


Figure 1. Active tag emulation system overview

1.2. Active Tag Communication Emulation

The active tags employed in the pedestrian localization experiment use wireless communication to exchange information with each other. Therefore we must be able to recreate with sufficient realism the communication between the emulated active tags. This was accomplished by extending the WLAN emulator QOMET [1] to support the wireless transceiver used by active tags. QOMET uses an XML scenario-driven architecture that has two stages. In the first stage, from a real-world scenario representation we create a network quality degradation (ΔQ) description which corresponds to the real-world events (see Figure 2). This is done by modeling the effects at the different layers of the communication protocol, from physical to data link layer. Then we apply in real time the ΔQ description to the traffic communicated during the effective emulation process so as to replicate the user defined scenario.

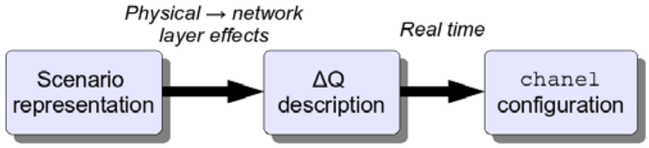


Figure 2. Scenario-driven two-stage emulation

The model used in QOMET to obtain the ΔQ description that corresponds to the active tag communication conditions in a certain user-defined scenario is an aggregation of several models used at the various steps of the conversion needed to recreate that scenario's conditions; more details on these models can be found in [7].

Given that the active tags do not generate IP traffic, as usual PC applications, we decided to implement *chanel* (CHANnel Emulation Library). This module is inserted between the space emulating the tags (Active Tag Control Space in **Figure 1**) and its connection to the other spaces. The main role of *chanel* is to recreate scenario-specific communication conditions based on the ΔQ description (FER probabilities) computed by QOMET. A second function of *chanel* is to make sure the data is communicated to all the systems that would receive it during the corresponding real-world scenario.

1.3. Active Tag Processor Emulation

We emulate the active tag processor so that the active tag firmware can be run in our emulated environment without any modification or recompilation. Processor emulation in our system had to take into account the following aspects that we implemented: (i) instruction execution emulation; (ii) data I/O emulation; (iii) interrupt emulation.

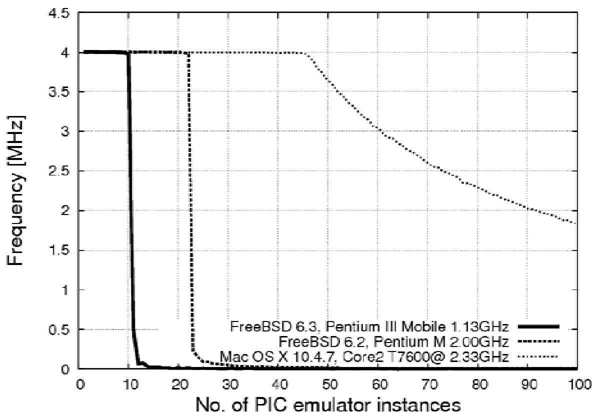
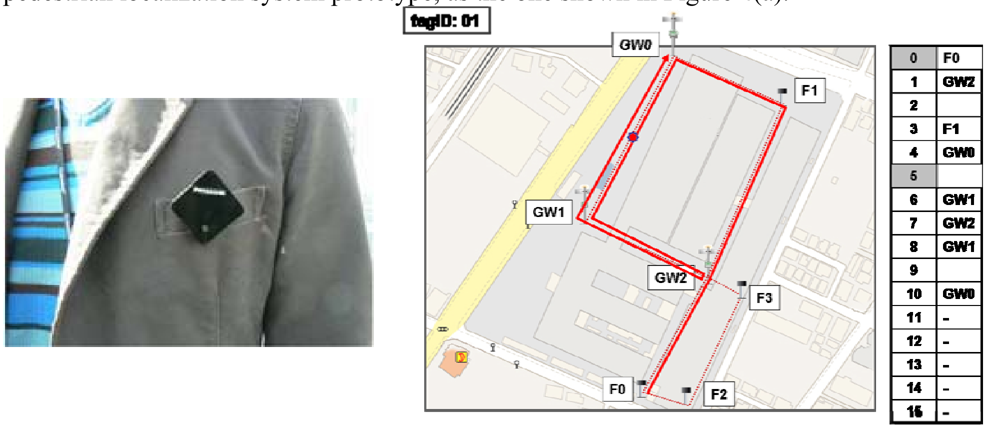


Figure 3. PIC emulator frequency accuracy depending on the number of executed instances

When emulating active tag applications such as ours it is important to introduce cycle-accurate processor emulation. In our case active tags use the time information contained in messages to synchronize with each others autonomously. Incorrect time information may lead to artificial desynchronization problems and potentially communication errors, therefore it must be avoided. In Figure 3 we show how emulation accuracy changes depending on the computing platform used and the number of instances of the PIC emulator that are run in parallel. We remind that the intended execution frequency is 4 MHz. Given a sufficiently powerful platform, good accuracy is obtained for up to about 45 instances running in parallel. Nevertheless, even with the less powerful platforms we still managed to have at least 10 PIC emulator instances running at the intended execution frequency.

2. Real-world Experiment

The real-world experiment was carried out in March 2007 by Matsushita Electric Industrial Co., Ltd. Each experiment participant was equipped with an active tag based pedestrian localization system prototype, as the one shown in Figure 4(a).



(a) (b)

Figure 4. Real world experiment: (a) participant wearing an active tag; (b) movement instructions as received by participant #1

2.1. Experiment Description

The 16 participants were each provided with instructions regarding the path they should follow in the 100 x 300 m experiment area. The instructions indicated the experiment topology, as well as the time in minutes when each known location should be reached. An example of instructions, as received by participant #1 is shown in Figure 4(b).

The experiment was scheduled to last 15 minutes, and followed a scenario in which a disaster situation leads to the necessity of area evacuation. After 5 minutes of unrelated walking patterns for each of the individual pedestrians and couples of pedestrians, it was considered that an event took place, such as a fire or earthquake, which required an evacuation procedure. Following this event all pedestrians' instructions were to proceed to an assembly point located in the upper left corner of the area (GW0 in Figure 4(b)). Participants also received a stopwatch, to try to ensure they follow as closely as possible the indicated scenario, and a GPS receiver for an external confirmation of their position.

The real-world experiment also included a number of tags with known position. These tags are divided into two classes: fixed and gateway tags, denoted in Figure 4(b) by F0 to F3, and GW0 to GW2, respectively. Fixed tags cannot communicate information except by using the tag protocol and wireless network. They are placed at 4 known locations, both outdoors and indoors. The role of fixed tags is to communicate with the mobile tags that come in their vicinity and makes it possible to determine the absolute location of those tags. Gateway tags, in addition to tag communication, also allow information to be transferred to the outside world by using the IEEE 802.11j standard. The gateways are placed at 3 known outdoor locations and are connected to each other in an ad-hoc style network. Gateways are also connected to the Internet; the log data they receive from mobile tags is used to determine the trajectories and positions of pedestrians.

2.2. Localization Technique and Discussion

The real-world experiment was successful in the sense that data collected from the active tags could be used to localize the pedestrians in most cases with sufficient accuracy. The tag log information is used to predict the trajectory of tag wearers and track their position. The basic equation used to calculate the position P_x of a pedestrian at moment of time t_x is:

$$P_x = P_i + \left(P_j - P_i\right)\frac{t_x - t_i}{t_j - t_i}, \tag{1}$$

where P_i and P_j are the known positions of the pedestrian (from tag logs) at moments of time t_i and t_j, with $t_i \leq t_x \leq t_j$. For more details about the experiment and the pedestrian localization engine one may consult [4] (in Japanese).

While experimenting with the prototype active tag based localization system under various circumstances, a series of problems were identified:

- The wireless communication between the prototype active tags was not always reliable; in addition, battery depletion was relatively fast and caused signal to weaken during and between experiments;
- Orchestrating a real-world experiment using even as few as 16 people is a cumbersome task (to perform the 15 minutes experiment it took actually a few hours of preparation);
- The off-the-shelf GPS receiver used had difficulties in providing a reliable location for small scale movements; in addition, they could not be used inside buildings.

Table 1 below shows a summary of the main differences between position localization using cellular phones with GPS capabilities (that transmit their position via the cellular phone network), and our active tag based technique.

Table 1. Comparison between cellular phone with GPS and active tag based location tracking techniques

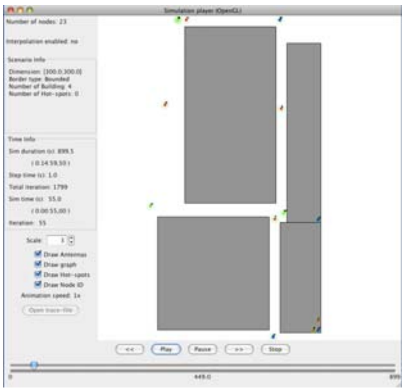
Cellular phone w. GPS	Active tag system
Snapshot of position	Track movement continuously
Paging each terminal	Track many tags at a time

Not available in disaster	Potentially more reliable
Outdoors use only	Outdoors/indoors/underground
High power	Low power

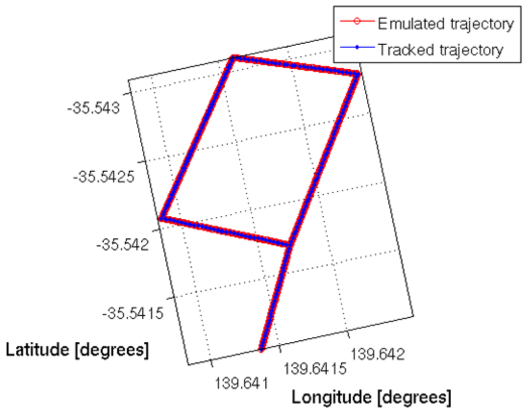
3. Emulation Results

The emulation experiment shown below uses exactly the same conditions as the real-world experiment described in Section 2, and was used to validate the emulation system. For simplicity each active tag and the associated *chanel* component were run on one PC. Movement of the nodes in the virtual environment is visualized using an interface based on MOMOSE [8], for which a screen caption is shown in Figure 5(a). We obtained a good agreement between the trajectory of the pedestrian and the positions localized by the system. As it can be seen in Figure 5(b), the emulated trajectory on which pedestrians moved in the virtual environment during the emulation experiment (cf. Figure 4(b)), and the trajectory tracked by the localization engine correspond very well.

Moreover, in our emulation system, communication between mobile nodes and fixed nodes only takes place when the mobile node is in the vicinity of a fixed node, exactly as it would happen in reality due to the short communication range of active tags. This proves that mobile node motion in the virtual space and wireless communication condition recreation (using QOMET and *chanel*), as well as tag execution (using RUNE) are perfectly synchronized and in accordance with our expectations from the real-world experiment. By emulation experiments we were also able to identify some issues in the active tag firmware, for example related to time synchronization.



(a)



(b)

Figure 5. Experiment visualization: (a) interface; (b) trajectory of pedestrian #1

4. Conclusions

In this paper we presented an emulation system that we designed and developed for active tag applications. This emulation system is currently employed for the development phase experiments of a pedestrian localization system by Matsushita Electric Industrial Co., Ltd. By using our system it was possible to simplify the development and testing procedures of the localization engine, and identify several firmware implementation issues.

In order to validate the emulation system we carried out tests that reproduced a real-world 16 pedestrian experiment that took place in March 2007 using the prototype of the active tag based pedestrian localization system. The emulation experiment results show the good agreement that exists between the virtual motion patterns of pedestrians, reproduced according to the real-world scenario, and the actual conditions that were recreated in our emulation experiment.

Our future work has several main directions, such as improving the scalability of the system so as to enable experiments of pedestrian groups as large as 1000; improving the realism of the wireless communication emulation by using more accurate 3D models for topology and electromagnetic wave propagation. For large-scale experiments, we intend to combine a behavioral pedestrian motion model with a GIS-based urban area description to create a realistic urban environment.

Acknowledgment

This work was supported in part by the Japan Science and Technology Agency (JST) under a grant of the 2007 3rd round of the Innovating Industry-University Collaboration Seeds project.

References

[1] R. Beuran, L. T. Nguyen, K. T. Latt, J. Nakata, Y. Shinoda, "QOMET: A Versatile WLAN Emulator", IEEE International Conference on Advanced Information Networking and Applications (AINA-07), Niagara Falls, Ontario, Canada, May 21-23, 2007, pp. 348-353.

[2] J. Nakata, T. Miyachi, R. Beuran, K. Chinen, S. Uda, K. Masui, Y. Tan, Y. Shinoda, "StarBED2: Large-scale, Realistic and Real-time Testbed for Ubiquitous Networks", TridentCom 2007, Orlando, Florida, U.S.A., May 21-23, 2007.

[3] A. Janek, Ch. Trummer, Ch. Steger, R. Weiss, J. Preishuber-Pfluegl, M. Pistauer, "Simulation Based Verification of Energy Storage Architectures for Higher Class Tags supported by Energy Harvesting Devices", 10th Euromicro Conference on Digital System Design Architectures, Methods and Tools (DSD 2007), Lubeck, Germany, Aug. 29-31, 2007, pp. 463-462.

[4] Y. Suzuki, T. Kawakami, M. Yokobori, K. Miyamoto, "A Real-Space Network Using Bi-Directional Communication Tags – Pedestrian Localization Technique and Prototype Evaluation", IEICE Forum on Ubiquitous and Sensor Networks, technical report, October 30-31, 2007.

[5] Ymatic, Inc., http://www.ymatic.co.jp.

[6] Microchip Technology, Inc., http://www.microchip.com/.

[7] J. Nakata, R. Beuran, T. Kawakami, K. Chinen, Y. Tan, Y. Shinoda, "Distributed Emulator for a Pedestrian Tracking System Using Active Tags", 2nd International Conference on Mobile Ubiquitous Computing, Systems, Services and Technologies (UBICOMM2008), Valencia, Spain, Sep. 29–Oct. 4, 2008 (accepted for publication).

[8] S. Boschi, P. Crescenzi, M. Di Ianni, G. Rossi, P. Vocca, "MOMOSE: A Mobility Model Simulation Environment for Mobile Wireless Ad-hoc Networks", 1st International Conference on Simulation Tools and Techniques for Communications, Networks and Systems (SIMUTools 2008), Marseille, France, March 3-7, 2008.