Scientific Report

First name / Family name	Chamath Keppitiyagama
Nationality	Sri Lankan
Name of the *Host Organisation*	SICS Swedish ICT AB
First Name / family name of the *Scientific Coordinator*	Thiemo Voigt
Period of the fellowship	01/04/2013 to 31/03/2014

I – SCIENTIFIC ACTIVITY DURING YOUR FELLOWSHIP

I started my research work at SICS with the intention of exploring the possibilities of using sensors to improve routing in sensor networks. At that time SICS has already started working on an EU project called RELYonIT, which has the objective of proving guaranteed performance for sensor networks operating in harsh environments. Several European organizations, including SICS, are partners in this project and SICS has the responsibility (among others) to look into providing guaranteed performance in the routing layer. My advisor pointed out that the broader goal of my intended research neatly fits in with the work of the RELYonIT project and I started working with the RELYonIT team. More specifically, I worked with the team that explores the effect of the temperature on the link quality and routing.

First we investigated the effect of temperature on the radios used by the popular motes and then we developed a mathematical model to describe the effect of temperature on received signal strength. In addition, we have also identified the possible cause of the reduction in the received signal strength and the transmission power due to the temperature.

In the next phase we investigated the effect of temperature on the RPL routing protocol using the TempLab testbed at the TU Graz. We observed that temperature negatively affects RPL. This observation led us to develop a new version of RPL using the platform models and environmental models developed by different teams of the RELYonIT project. At the time of competing my fellowship we are in the process of studying the behaviour of this new protocol under temperature changes.

In addition to the work mentioned above I have served as the member of the program committee of the REALWSN'13 and reviewed papers for the ACM Transactions on Sensor Networks and the Wireless Networks (WINET) journal published by the Springer.

II – PUBLICATION(S) DURING YOUR FELLOWSHIP

- Boano, Carlo Alberto and Wennerström, Hjalmar and Zúñiga, Marco Antonio and Brown, James and **Keppitiyagama, Chamath** and Oppermann, Felix and Roedig, Utz and Nordén, Lars-Åke and Voigt, Thiemo and Römer, Kay (2013) *Hot Packets: A Systematic Evaluation of the Effect of Temperature on Low Power Wireless Transceivers.* In: IEEE ExtremeCom 2013. (Published)

  Abstract: *Temperature is known to have a significant effect on the performance of radio transceivers: the higher the temperature, the lower the quality of links. Analysing this effect is particularly important in sensor networks because several applications are exposed to harsh environmental conditions. Daily or hourly changes in temperature can dramatically reduce the throughput, increase the delay, or even lead to network partitions. A few studies have quantified the impact of temperature on low-power wireless links, but only for a limited temperature range and on a single radio transceiver. Building on top of these preliminary*

observations, we design a low-cost experimental infrastructure to vary the on-board temperature of sensor nodes in a repeatable fashion, and we study systematically the impact of temperature on various sensornet platforms. We show that temperature affects transmitting and receiving nodes differently, and that all platforms follow a similar trend that can be captured in a simple first-order model. This work represents an initial stepping stone aimed at predicting the performance of a network considering the particular temperature profile of a given environment.

- **Keppitiyagama, Chamath** and Tsiftes, Nicolas and Boano, Carlo Alberto and Thiemo, Voigt (2013) *Poster Abstract: Temperature Hints for Sensornet Routing.* In: SenSys13 (Published)

  Abstract: *Real-world experiments have shown that the transmission power and the received signal strength of low-power radio transceivers used in sensornets decrease when temperature increases. We analyze how this phenomenon affects the network layer, and find that temperature fluctuations may cause undesirable behavior by sensornet routing protocols such as CTP and RPL. Furthermore, we present an approach to make these protocols robust to temperature fluctuations by augmenting the ETX link metric with temperature hints.*

- Boano, Carlo Alberto and Zuniga, Marco Antonio and Brown, James and Roedig, Utz and **Keppitiyagama, Chamath** and Roemer, Kay (2014) *TempLab: a testbed infrastructure to study the impact of temperature on wireless sensor networks.* In: Proceedings of the 13th International Conference on Information Processing in Sensor Networks (IPSN '14). ACM. (In Press)

  Abstract: *Temperature has a strong impact on the operations of all electrical and electronic components. In wireless sensor nodes, temperature variations can lead to loss of synchronization, degradation of the link quality, or early battery depletion, and can therefore affect key network metrics such as throughput, delay, and lifetime. Considering that most outdoor deployments are exposed to strong temperature variations across time and space, a deep understanding of how temperature affects network protocols is fundamental to comprehend flaws in their design and to improve their performance. Existing testbed infrastructures, however, do not allow to systematically study the impact of temperature on wireless sensor networks. In this paper we present TempLab, an extension for wireless sensor network testbeds that allows to control the on-board temperature of sensor nodes and to study the effects of tem- perature variations on the network performance in a precise and repeatable fashion. TempLab can accurately reproduce traces recorded in outdoor environments with fine granularity, while minimizing the hardware costs and configuration overhead. We use TempLab to analyse the detrimental effects of temperature variations (i) on processing performance, (ii) on a tree routing protocol, and (iii) on CSMA-based MAC protocols, deriving insights that would have not been revealed using existing testbed installations.*

- Zúñiga, Marco Antonio and Boano, Carlo Alberto and Brown, James and **Keppitiyagama, Chamath** and Oppermann, Felix Jonathan and PAlcock, Paul and Tsiftes, Nicolas and Roedig, Utz and RömerL, Kay ad Voigt, Thiemo and Langendoen, Koen (2013) D-1.1 Report on Environmental and Platform Models , Published by RELYonIT Consortium (Published)

  Abstract: *This deliverable describes the progress made on the platform and during the first eight months of work. This progress is related to Tasks 1.1 and 1.2 in the Description of Work. The overarching goals of these two tasks are: (i) to capture the relevant temporal and spatial distribution of environmental properties, in particular, temperature and interference; and (ii) to develop platform models that capture how those environmental properties affect the signal strength, timing, sensing accuracy, and energy consumption of WSAN hardware platforms. During these first eight months, our focus has been on analysing the effect of temperature. We now have a thorough understanding of the effect the temperature on the signal strength and a good understanding of the effect of temperature on timing. We have also started to evaluate the effect of temperature on sensing and energy consumption. With respect to interference, we have started to de□ne some initial analytical models to capture the bursty nature of various interference sources.*

III – ATTENDED SEMINARS, WORKHOPS, CONFERENCES

- CSL Conference, 2013-06-17 /18, Bergendal, Sollentuna Sweden
- SICS Software Week, 2013-09-23, Kista, Sweden
- ERCIM Seminar, 2013-10-31 – 2013-11-01, Athens, Greece
- ACM Conference on Embedded Networked Sensor Systems (SenSys 2013), 2013-11-11 to 2013-11-14, Rome, Italy
- CSL and DNA joint meeting, 2014-01-23, SICS, Kista, Sweden

IV – RESEARCH EXCHANGE PROGRAMME (REP)

1. Organization: Institute of Computer Science (ICS) of the Foundation for Research and Technology - Hellas (FORTH)
   Country: Greece
   Dates: 2013-11-25 to 2013-11-29
   Local Scientific Coordinator: Prof. Maria Papadopouli

   Work carried out during the visit:

- Presentation on Sensor Hints for Sensornet Routing
- Discussions with students/researchers
- Guest lecture at the University of Crete on Routing in Sensor Networks

2. Organization: University of Geneva (UNIGE)
   Department: TCS-Sensor Lab at the Centre Universitaire d'Informatique
   Dates: 2014-02-03 to 2014-02-07
   Local Scientific Coordinator: Prof. José Rolim

   Work carried out during the visit:
- Presentation on Sensor Hints for Sensornet Routing
- Discussions/Meetings with researchers