Approaches to Node and Service Discovery in 6lowPAN

V. Leithardt[1], C. Geyer[1], R. Silva[2], J. Sá Silva[2], F. Boavida[2], J. Rodrigues[3]

[1]Grupo de Processamento Paralelo e Distribuído
Instituto de Informática
Universidade Federal do Rio Grande do Sul
Caixa Postal 15.064 - 91.501-970, Porto Alegre, RS, BRASIL
{vrqleithardt, geyer}@inf.ufrgs.br

[2]Departamento de Engenharia Informática
University of Coimbra
Pólo II - Pinhal de Marrocos, 3030-290 Coimbra
rnsilva@student.dei.uc.pt, {sasilva, boavida}@dei.uc.pt

[3]Instituto de Telecomunicações
Department of Informatics
University of Beira Interior
Rua Marques D'Avila e Bolama, 6201-001, Covilha, Portugal
joel@ubi.pt

Abstract

Discovering nodes and services in Wireless Sensor Networks poses several challenges. Different sink and sensor nodes announcement strategies lead to different amounts of resource consumption in terms of processing, memory, communication time and drained energy. This may be aggravated if IP is the underlying protocol, such as in the case of 6lowPAN networks. In this paper three paradigms for node and service discovery are proposed, analyzed and evaluated. The results, obtained by prototyping, shows that at least one of the proposed strategies leads to efficient use of resources, showing that node and service discovery in resource-constrained networks such as 6lowPAN is feasible.

1. Introduction

In the recent years, the evolution of sensor networks has been extreme due to the combined effect of enabling technologies and pressing application needs. The basic components of sensors nodes, also called motes, are the transducers, elements capable of measuring physical parameters, such as temperatures, light intensity or pressure, and of converting them from analog to digital form. Another fundamental component is the communication module, supporting wired or wireless communication. The combination of wireless communication capabilities with sensing capabilities and data processing has led to the concept of wireless sensor network (WSN) and to a myriad of potential applications. However, many of these applications require that the sensor nodes are deployed in places that are not easily reachable or that are even unknown [1, 2]. Thus, motes are basically stand-alone devices that, after deployment, are not recovered and must operate with their initial energy source only.

However, some MAC [13], layer protocols already provides some support for node mobility as well as for services discovery. MS-MAC [3], MAMAC [4] and MHMAC [5] are just examples. This paper presents and proposes three approaches to discover devices and services in wireless sensor networks. The first approach, called "YouCatchMe", follows the philosophy of conventional wireless networks, where an access point periodically sends beacons, announcing their presence. The second approach looks at the issue from a different perspective: in the "ICatchYou" approach, sink nodes are in silent and it is the responsibility of each sensor node to search and detect sink nodes. Lastly, "Some1CatchMe" makes use of RFID tags and readers to discover sensor nodes. All of the proposed approaches were implemented, in order to study and evaluate them.

This paper is organized as follows. Section 2 introduces and describes the proposed paradigms for service and node discovery. Section 3, in which this comparison is extended to the results obtained through implementation, in order to better assess the impact of the proposed service discovery mechanisms, as well as the impact of using IP-based solutions. Conclusions and guidelines for further works are presented in the Section 4.

2. Node and service discovery in wireless sensor networks

2.1. Motivations for node and service discovery

Although WSNs can be used in static environments, dynamic environments are the ones for which WSNs have the highest potential use. In fact, if we consider typical WSN characteristics, such as energy constraints, unmanned deployment and operation, almost all designed WSNs are theoretically dynamic, even if the nodes are fixed. Dynamic environments typically are designed and account for node mobility. In such an environment, a node should be able to dynamically switch between different WSNs and perform auto configuration, repeating the process whenever is needed, several times during the mote's lifetime. As example scenario, we can consider a hospital where each patient carries one or more sensors that are monitoring various life signals. Some patients are bedfast, while others can walk around the facilities, for instance, to go into the main room to watch television, or to have lunch at the canteen. In order to get the sensor nodes measured values, the hospital can install one sink node per room. Each time patients move from one room to another, their own sensor nodes have to be integrated into the new WSN of that room.

2.2. Overview of proposed approaches

Three approaches to node and service discovery are proposed in this paper: "YouCatchMe", "ICatchYou" and "Some1CatchMe". This sub-section provides an overview of each of these approaches. The YouCatchMe node/service discovery paradigm relies on active sink nodes: a sink node periodically broadcasts announcements (Router Advertisements). Upon arrival at a new network, wireless sensor nodes receive the sink node announcements, initiate the registration procedure and indicate the services they support to the sink node. The sink node knows in real time which nodes are in the area and what services they provide. The ICatchYou node/service discovery paradigm is based on a completely different approach: instead of having the sink node sending announcements, it is the sensor node that, after deployment or when it arrives at a new network, starts sending requests for registration. This eliminates the need for sink node broadcast announcements (as opposed to YouCatchMe) but introduces a sensor node announcement. The Some1CatchMe discovery paradigm is based on a multi radio approach, as it resorts to RFID and IEEE 802.15.4 [14]. In order to avoid the periodic broadcasts of YouCatchMe or the Router Solicitations of ICatchYou, Some1CatchMe uses RFID to discover the new nodes within the network range. Upon arrival at a new network, nodes equipped with an RFID tag are discovered by a local RFID reader, which is connected to the local sink node. After detection of a new sensor node, the sink node initiates the registration procedure, communicating directly with this new node. Since all power used in RFID comes from the RFID reader, motes do not spend energy during the discovery procedure. The technology has been used in several applications, especially those that require low power consumption. In the next subsections each of these approaches will be presented in more details, namely in what concerns the discovery and registration phases and message exchange.

2.3. YouCatchMe

In YouCatchMe, sink nodes send beacons to announce their presence. These use the ICMPv6 protocol [7] in order to periodically send Router Advertisements (RA) to the broadcast address. After deployment or upon arrival at a new WSN, sensor nodes start receiving the beacons and answer with an acknowledgement. On their turn, sink nodes validate the received acknowledgement messages and maintain a database of registered sensor nodes. This database can be used by applications to know which sensor nodes, and respective services, are available. The YouCatchMe operation is based on a fixed cycle comprising three different periods: the B (broadcast) period, in which RA messages are broadcasted; the L (listening) period, in which acknowledgement messages are received and processed; and the S (sleep) period, during which no node discovery activity takes place, leaving room to data exchange with the sensors. Sink nodes maintain a database containing only the nodes that responded to the most recent beacon, and these are the ones that are considered active in the current period P_i, where $i \in N$ [13]. For instance the nodes detected in P_i could be different from the ones detected in P_{i+1}.

2.4. ICatchYou

ICatchYou was designed to minimize the exchange of broadcast messages. In this approach the deployed nodes have the responsibility of to find the most suitable sink node and start the registration process. The underlying discovery/registration protocol comprises an initial registration phase, a TTL, the TTL values used was defined in [13].phase and subsequent update/TTL phases (see Figure 1).

Figure 1. ICatchYou operation time line.

The proposed protocol was designed and implemented as an ICMPv6 extension, using free messages types for each protocol step. It is clearly an extension of Neighbor Discovery, using also the Router Solicitation (RS) and Router Advertisement (RA) messages. Figure 2 shows the implemented registration and update procedures.

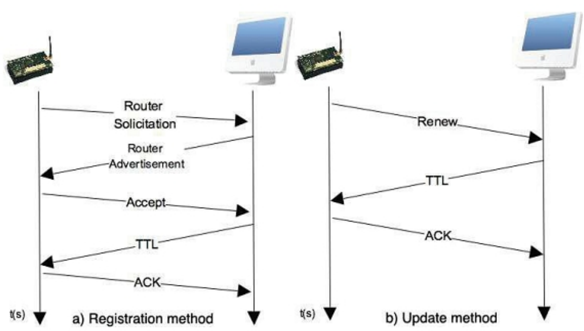

Figure 2. ICatchYou protocol.

The registration procedure (Figure 2a) starts with a Router Solicitation (RS) message, sent from a node to the sink nodes multicast/anycast address. Upon reception of an RS message, sink nodes reply with an RA message. Through this reply the node checks the link quality, selects the sink node with the best link quality and sends it the ACCEPT message. After reception of an ACCEPT message, the sink node assigns a TTL value to the new node. When the node receives the TTL, it self configures its IPv6 global address, according to the network prefix of the sink node, replies with an ACK message, initiate a timer with the TTL value and proceeds to countdown until achieves the update phase (U) threshold value. When the node enters the update phase, it sends the RENEW message directly to its sink node. In normal conditions, the sink node receives the command, checks the database to validate it and assigns a new TTL value. Otherwise, if the sink node is no longer available, the update period will expire and the node will start the registration process. A study of TTL impact will be presented in section 3.

2.5. Some1CatchMe

Some1CatchMe makes use of RFID tags associated to IEEE 802.15.4 [6]. RFID tags do not process anything. They just contain an identification that can be read by RFID readers. All energy to read the tag comes from the RFID reader; hence, if we associate a tag to a node, the RFID reader can discover it without energy consumption by the node. Thus, upon arrival of a sensor node to a new network, the sink node RFID reader reads the RFID tag of the sensor node, containing the IEEE 802.15.4 EUI 64 bits address. This allows the sink node to communicate with the new sensor node, using the Link Local IPv6 address obtained from the Layer-2 64-bits address [8]. When a sink node detects a new node, it initiates a registration process similar to the one presented for ICatchYou, using a TTL as well. Comparing the registration procedure of Some1CatchMe with that of ICatchYou (Figure 2a), the Router Solicitations disappear. Thus, the node discovery process is completely transparent to the sensor node itself. The node only becomes aware of the registration process when it receives a unicast RA from the sink node. Considering that the node can receive RAs from different sink nodes, it can also choose the best one based on the link quality, as in the ICatchYou case. The Update method is the same as in ICatchYou.

3. Impact of Node/Service discovery mecanisms

In order to evaluate the impact of the presented architectures, from an point of view about of energy consumption, a real test was performed in [13]. All studies were developed over a 6lowPAN implementation [9], included in the latest TinyOS CVS version [11,12]. This implementation supports UDP communication and ICMPv6. The used hardware was the MicaZ motes and the mib520 USB board, both from Crossbow [5]. The three mechanisms - that is, YouCatchMe, ICatchYou and Some1CatchMe - were implemented. Subsequently, energy consumption was calculated, based on the measurement of the electric current (mA). The electric current of motes highly depends on the operation mode, more specifically, on the fact that the mote radio transceiver is *on* or *off*, and if it is transmitting or not. The amount of energy spent in a given time frame, t, can be calculated using (1), where V is the battery voltage (approximately constant) and I is the measured current. The total amount of energy consumed in a mixed operation period (i.e., with radio off, radio on, and radio on with transmission) is given by (2).

$$Et = V \times I \times t \tag{1}$$

$$E_{Total} = E_{radioOff} + E_{radioOn} + E_{radioTransmitting} \tag{2}$$

YouCatchMe and ICatchYou have a particular behavior that, at first, gives advantage to ICatchYou for T = TLL < 50 and, for n = TTL > 50, to YouCatchMe. The complexity of Some1CatchMe is relied on a multi-radio platform using RFID. Nodes become dynamically available in a new network, without any energetic effort. To choose between ICatchYou and Some1CatchMe, a relation about effective cost must be taken in consideration, where the additional cost of the RFID system counterbalance or not the additional energy spent with ICatchYou.

4. Conclusion

Current paper has addressed the problem of service and node discovery in wireless sensor networks using the 6lowPAN framework. In this context, three paradigms were proposed, analyzed and evaluated, having in mind the resource restrictions that are typical of WSNs. Although the proposed solutions uses IPv6 as the underlying protocol and requires some simple higher layer mechanisms, the evaluation results clearly show that at least two of them - the ICatchYou and Some1CatchMe approaches - lead to good performance and thus do not imply high resource consumption. Moreover, if the kind of application allows it, Some1CatchMe is able to eliminate broadcasts, which makes it the most energy efficient method for node and service discovery. Future works will be directed towards the improvement and refinement of the ICatchYou and Some1CatchMe approaches, specifically in what concerns the motes' capability to select the best access point, to self configure IPv6 global addresses, and to support single or multiple access points per network, among others. This will be fundamental for the success of the wider multi-sink, IPv6-based, mobility-enabled WSN architecture underlying the presented node and service discovery mechanisms.

References

[1] N. Kushalnagar, G. Montenegro, and C. Shumacher. Ipv6 over low-power wireless personal - A Area networks (6lowpans). *RFC* 4919, August 2004.

[2] G. Montenegro, N. Kushalnagar, J. Hui, and D. Culler. Transmission of ipv6 packets over ieee802.15.4 networks. *RFC* 4944, September 2007.

[3] Huan Pham and Sanjay Jha. Addressing mobility in wireless sensor media access protocol. Intelligent Sensors, Sensor Networks and Information Processing Conference, 2004. *Proceedings of the 2004*: 113-118, Dec. 2004.

[4] Liu Bing, Yu Ke, Zhang Lin, and Zhang Huimin. Mac performance and improvement in mobile wireless sensor networks. Software Engineering, Artificial Intelligence, Networking, and Parallel/Distributed Computing, 2007. SNPD 2007. *Eighth ACIS International Conference on*, 3:109-114, 30 2007-Aug. 1 2007.

[5] L. Bernardo, R. Oliveira, M. Pereira, M. Macedo, and P. Pinto. A wireless sensor mac protocol for bursty data traffic. Personal, Indoor and Mobile Radio Communications, 2007. PIMRC 2007. *IEEE 18th International Symposium on*: 1-5, Sept. 2007.

[6] Rfid website, *www.epcglobalinc.org*, 2009.

[7] Z. Shelby, P. Thubert, J. Hui, S. Chakrabarti, and E. Nordmark. *Neighbor discovery for 6lowpan draft-ietf-6lowpan-nd-00*, 2008.

[8] L. Toutain, G. Chelius, Y. Lee, and Y. Dong. *Neighbor discovery suppression draft-toutain-6lowpan-ra-suppression-00.txt*, 2008.

[9] M. Harvan. *Connecting wireless sensor networks to the internet - a 6lowpan implementation for tinyos 2.0*, In Jacobs University Bremen, Germany, 2007.

[10] The xbow website, *http://www.xbow.com*, 2009.

[11] The tinyos website, *http://www.tinyos.org/*, 2009.

[12] The nesc website *http: //nescc.sourceforge.net/*, 2009.

[13] R. Silva, V. Leithardt, J. Silva, J. Rodrigues, F. Boavida; A Comparison of Approaches to Node and Service Discovery in 6lowPAN Wireless Sensor Networks, *5-th ACM International Symposium on QoS and Security for Wireless and Mobile Networks*. Q2SWinet, 2009.

[14] G. Montenegro, N. Kushalnagar, J. Hui, and D. Culler. Transmission of ipv6 packets over ieee802.15.4 networks. *RFC* 4944, September 2007.