MIPv6 Soft Hand-off for Multi-Sink Wireless Sensor Networks

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1. Introduction

Although Wireless Sensor Networks (WSNs) are one of the most promising technologies of the 21st century - with potential applications in virtually all areas of activity, ranging from the personal area to the global environment - a considerable number of challenges has still to be addressed in order to make WSNs a day-to-day reality. First of all, reachability issues (including IP connectivity, addressing and routing) must be solved. Then, other problems such as self-configuration, quality of service, and security must also be tackled. A crucial aspect, however, is mobility. Many applications require sensor mobility, and either network mobility, to be effective. Some examples include the use of WSNs for vehicle monitoring and control, or health parameters monitoring of ambulatory patients. Without efficient mobility mechanisms, the application areas of WSNs will be highly restricted.

In terms of WSN reachability, there is clear movement towards the adoption of IPv6. The use of IP in sensor nodes has considerable benefits in terms of connectivity, and IPv6 has several advantages when compared to IPv4, the most prominent being the much larger address space. There are, nonetheless, other important advantages of IPv6, such as native support for mobility, anycast addressing, security and self-configuration.

Recently, the IETF created the 6LowPAN group Mulligan (2008) to study the integration of IPv6 in simple IEEE 802.15.4 wireless devices. 6LowPAN proposes a middleware layer to integrate IPv6 in WSNs. Concerning packet headers, although the IPv6 header is simpler when compared to the IPv4 header, it is larger because of the use of 128-bit addresses, as opposed to the 32-bit addresses in IPv4. To circumvent this, 6LowPAN proposes the use of compressed headers.

There are already some implementations of 6LowPAN modules for the TinyOS and Contiki operating systems. However, mobility is not yet supported in these IPv6-over-WSNs environments.

Although mobility of WSNs has been addressed in the recent past, most of the existing work assumes mobility of the whole WSN (i.e., of sink nodes) Dantu (2005) Labrindis (2005) Raviraj (2005), leaving out the issue of sensor node mobility. There are, nevertheless, some models Ekici (2006) Heidemann (2002) that propose the use of MAC-layer protocols to support mobile sensor nodes registration. However, to the best of our knowledge, they do not address the integration of WSNs in the IP world.

In this paper we propose a framework for an effective support of mobility in WSNs. The innovative aspects of the framework consist of the use of mobile IPv6 (MIPv6) in wireless sensor networks, the use of Neighbor Discovery for discovery of sink nodes and subsequent node registration and, last but not least, the use of a soft hand-off approach which prevents connectivity breaks while the sensor nodes are moving. Section 2 presents the proposed framework, including the sink node discovery and soft hand-off mechanisms. The framework has been evaluated through implementation, and the obtained results are presented in section 3. Section 4 provides the conclusions and guidelines for further research.

2. Proposed Framework

The proposed framework has the objective of efficiently dealing with the main requirements of wireless sensor networks, with the aim of overcoming some of the most important obstacles that prevent real world WSN deployments. The distinguishing features of the framework are the following:

- Multi-sink approach, in order to simplify routing; this precludes the need for complex and unrealistic multi-hop routing protocols and drastically reduces node energy constraints;
- Use of Mobile IPv6, thus leading to the availability of generalised IP connectivity and of native mobility;
- Soft hand-off approach, thus maximising the connectivity of mobile sensor nodes;
- Link quality prediction, allowing sensor nodes to decide if hand-off to other sink node is beneficial and/or feasible.

In the following sub-sections, these features and their underlying mechanisms will be addressed and explained in detail.

2.1 Sink Discovery and Node Registration

Two basic types of topologies can be used in WSNs: Single-sink multi-hop topology, also known as mesh topology, and multi-sink single-hop topology, also known as star topology.

In mesh topologies, all sensor nodes perform not only sensing tasks but also routing tasks, forwarding data towards the sink node through neighbouring nodes. At first glance, multi-hop communication appears to be more energy-efficient when compared to long-range single-hop communication, due to the fact that mesh topologies lead to shorter distances between transmitter and receiver. However, the apparent energy optimization of mesh topologies comes with too high a price, which is at the basis of the failure of real world WSN deployment: extreme complexity at various levels. In fact, mesh topologies require aggregation methods, signaling messages, increased memory, broadcast procedures, substantial overhead, complex routing protocols and/or large routing tables. This complexity is more critical in mobile environments. The dynamics of these environments causes changes in the network topology and, therefore, in routing, which leads to additional complexity and overhead.

Naturally, a mesh topology can be transformed into a star topology if several sink nodes are deployed, each covering a relatively small cell comprising several sensor nodes. In this case, energy-efficiency of sensor nodes can still be achieved Ð distances to a sink node can be kept small Ð and, in fact, sensor nodes can be simpler, as they do not need to forward packets or to perform complex routing tasks. The price to pay is the deployment of more sink nodes, but clearly in many cases it is easier to deploy more sink nodes than to use forbiddingly complex routing protocols.

However challenging and interesting might be the routing problem in mesh-based WSNs, the hard fact is that most (if not all) real applications of WSNs use a star topology. The reason is that with a star topology, the routing complexity disappears, and simple routing solutions can be adopted. This is, in fact, the rationale for using a multi-sink single-hop approach in the proposed framework, depicted in the scenario presented in Figure 1.

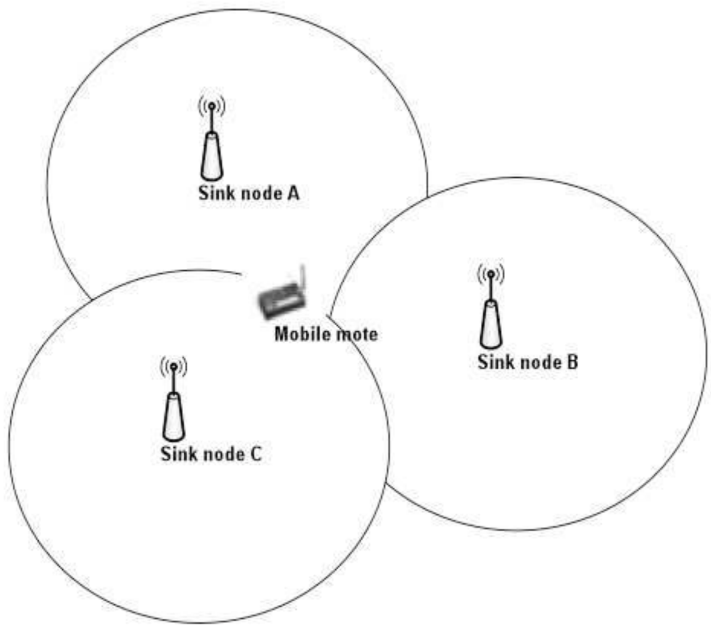


Fig. 1. Multi-Sink WSN mobility scenario

The use of multiple sink nodes must be accompanied by sink node discovery mechanisms which allow mobile sensor nodes to dynamically detect them and perform the necessary registration. The mechanism developed by the authors Ð based on preliminary work presented in Silva (2008) Ð is initiated by mobile sensor nodes, in order to avoid energy-expensive broadcasts from sink nodes. The underlying protocol is clearly an extension of the Neighbor Discovery protocol, and was implemented with the help of ICMPv6 extension messages. After choosing a sink node, mobile sensor nodes perform a registration operation, depicted in Figure 2a).

The registration operation consists of the following steps (see Fig. 2a):

1. Upon deployment, the node broadcasts a Router Solicitation (RS) message.
2. Sink nodes in range send back Router Advertisement (RA) messages.
3. The node collects the received RA messages and chooses the best sink node, based on the Received Signal Strength Indicator (RSSI) of each of the received message.
4. The node sends an acceptance message (ACCEPT) to the selected sink node.
5. The selected sink node receives the ACCEPT and responds with the TTL value to be used by the sensor node.
6. The node receives the TTL and self-configures its global address, based on the address prefix of the sink node.
7. The node sends an Acknowledgment message (ACK) to the sink node.
8. The sink node inserts the new sensor node in its Binding Table.

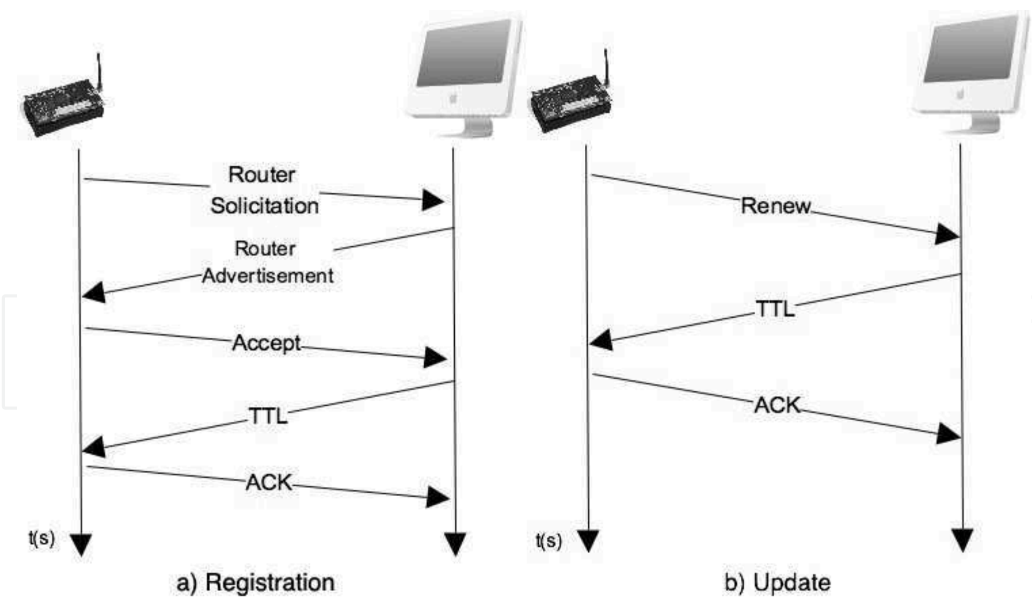


Fig. 2. Sink node discovery, registration and update

In the registration procedure the node uses the IPv6 stateless configuration mechanism to build its own address, using as prefix the one of the chosen network, and as suffix its Interface Identifier.

After registration, each node maintains a Time-To-Live (TTL) value. When this value becomes zero, the mobile node evaluates the signal strength and the Link Quality Indicator of all the sink nodes in the area to choose the best one. If the elected sink node is the one already in use by the mobile node, it is only necessary to start the update procedure (Figure 2b). If a new sink node is chosen, the registration procedure must be performed. The update procedure is simpler than the registration procedure, as the mobile node requests, using a unicast message, the revalidation of the registration.

2.2 Soft Hand-Off

In order to support node mobility, sink nodes maintain a binding table (see Table 1) with all their registered nodes, TTLs, supported services and nodesÕ Care-of-Address (CoA). Table 1 presents the various fields of the binding table.

Home Address	**TTL**	**List of Services**	**Care-of-Address**
Obtained during the node discovery procedure			<Null> or <New prefix + > Old sufix

Table 1. Binding Table

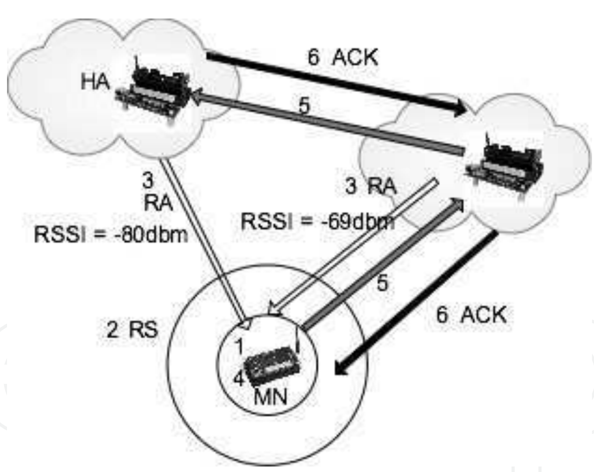
The first three fields of this table are filled in during the initial registration procedure. The CoA is initialised as null, being updated each time the node moves to a new foreign sub-network. The node, in turn, internally registers its Home Agent (Sink Node) Address, which remains the same while the current registration is valid.

If a node detects that the connection to its current sink node is in the critical zone Silva (2009), it initiates the sink node discovery/registration procedure described in section 2.1, by sending an RS message. Note that the new sink node discovery is performed before the connection to the current sink node is broken, in order to achieve a soft hand-off. This soft hand-off procedure is illustrated in Figure 3, below, and consists of the following steps:

1. The mobile sensor node (MN) detects a bad connection to the current sink node.
2. The MN broadcasts a Router Solicitation message (RS).
3. The MN receives (in the example) two Router Advertisements (RA).
4. The MN selects the sink node with the best received signal strength and re-configures its global address, changing the prefix to the one of the new sink node.
5. The MN sends a Binding Update message notifying the HA of its new COA, through the new link, guaranteeing that the message arrives there.
6. Upon reception of the Binding Update, the HA sends an Acknowledgement message to the MN and updates the COA in its Binding Table.

The choice of a new sink node should take into account not only the received RSSI, but also the nodeÕs velocity, the existing noise level and the mean time taken by hand-off operations. If a mobile node moves away from its current sink node with constant velocity $V(m/s)$, in an environment with noise level $N(dBm/m)$, and takes M seconds to perform the soft handoff, the link quality to its current sink node at the end of the hand-off can be estimated by:

$$Q_M = RSSI - (M \times V \times N) \tag{1}$$



Equation (1) can be used to predict the link quality at the end of the hand-off process and, thus, it can assist the decision on if and when to choose another sink node. For example, considering an RSSI of $-60dBm$, a 2 seconds mean hand-off time, a velocity of $2m/s$ and a noise level of $5dBm/m$, at the end of the handoff process the link quality would be:

$$Q_M = -60 - (2 \times 2 \times 5) \Leftrightarrow$$
$$Q_M = -80dBm$$

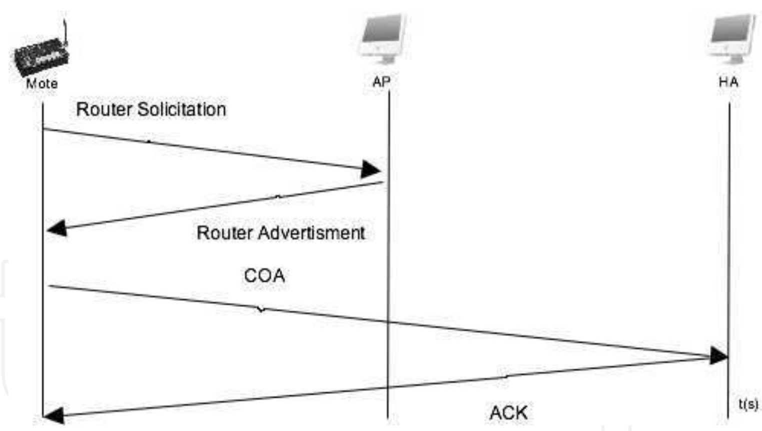


Fig. 3. Soft Handoff

The same formula can be applied not only to predict the link quality at the end of the hand-off, but also to predict the link quality within the home network, after M units of time. Such deductions are extremely useful to optimize the behaviour of sensor nodes in dynamic environments. Based on mobility and environment characteristics, nodes will be able to self adapt to a variety of situations.

If communication between a Correspondent Node (CN) and the Mobile Sensor Node (MN) is taking place during the hand-off, a transparent CoA update procedure is performed by the MN during the soft hand-off, as described above, and this leads to no message losses. This is complemented by a Binding Update sent by the Home Agent to the CN, in order to optimize subsequent communication instances. Figure 4 illustrates the process, which is comprises the following steps:

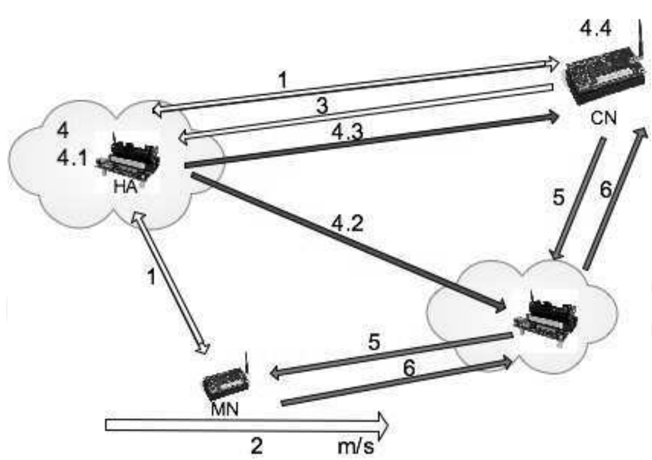


Fig. 4. Communication path update

1. The MN is communicating with CN.
2. The MN moves to a new attachment point.
3. The CN sends a message towards the HA:
4. The HA checks the CoA of the MN in the binding table.

4.1. The HA uses the CoA as the new destination address.

4.2. The HA tunnels the packet to the CoA.

4.3. The HA notifies the CN about the new CoA.

4.4. The CN Updates an internal Binding Cache.

5. The next time, the CN sends messages directly to the CoA.
6. The MN uses always its current attachment point to relay its messages.

3. Evaluation

To test and evaluate the performance of the proposed framework we implemented it in a real platform. We used MicaZ motes programmed with a 6lowPAN implementation Harvan (2007) modified according to our architecture. The sink nodes were Mib520 attached to ubuntu-based machines and running a special daemon, that we developed in C to support our framework. We used ICMPv6 message types 150 to 160 in order to implement the proposed framework supporting protocol. Additionally, we re-used the RA and RS messages from the Neighbor Discovery protocol.
The main purpose of the carried out test was the determination of the average duration of the soft handoff procedure. To measure this, we configured a network with two sink nodes and a mobile sensor node. Each sink node had two interfaces, one to the WSN and another to a local IPv6 network. Figure 5 illustrated the test-bed scenario. Wireshark was installed and used in order to monitor all packets and to control time, rates and delays. The test suites comprised three steps:

1. The initial registration of the MN in the HA, using the proposed procedure;
2. The movement of the MN;
3. The soft hand-off process.

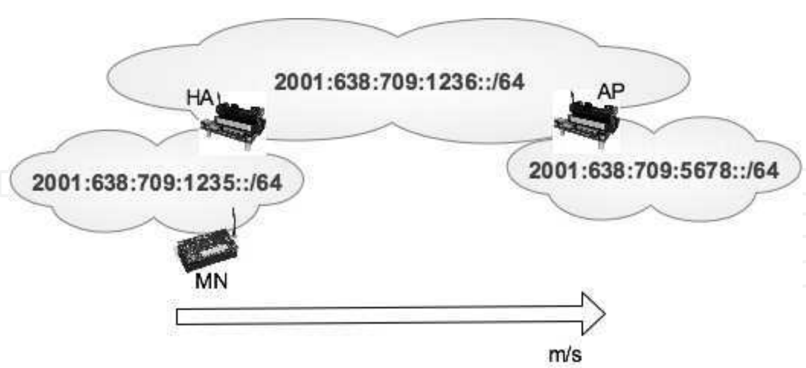


Fig. 5. Test-bed scenario

We measured the time elapsed since the node detects a quality degradation of the link connection to the HA, until it finishes the soft handoff process to the new attachment point. We performed 300 hand-off operations and corresponding measurements. The results are presented in table 2.

Minimum	Maximum	Mean	Std. deviation
2.081761	2.124737	2.10470933	.009944052

Table 2. Total soft-hand-off time (seconds), including the initial detection of signal quality degradation

The determined mean soft hand-off time can be used in conjunction with Equation (1) to estimate the quality of the sink connection under a variety of situations. For instance, as determined in Silva (2009) the minimum quality level guaranteeing connectivity (also known as rupture point) is $-88dBm$. Below this level, a hard hand-off must take place, that is, there will be and interruption of the connectivity. Using this value, the mean hand-off time determined in the tests and equation (1), it is possible to determine the maximum value for the product of velocity and noise (which we will represent by ΔC). Hence:

$$\begin{aligned} -88 &= -60 - (2.10470933 \times \Delta c) \Leftrightarrow \\ -28 &= -2.10470933 \times \Delta c \Leftrightarrow \\ \Delta c &=\sim 13.305 dBm/s \end{aligned}$$

In addition to obtaining the mean value for soft hand-off operations, the tests allowed us to verify the feasibility of the proposed framework, namely the use of the multi-sink approach, mobile IPv6, soft hand-off and link quality prediction.

4. Conclusion

Although considerable work has been and is being done in the area of wireless sensor networks, relatively few deployments exist. This is mainly due to the complexity inherent to multi-hop routing and to the lack of efficient mobility solutions.
In an attempt to circumvent these problems, we have proposed a framework that eliminates the need for multi-hop communication, uses mobile IPv6 as the basis for node mobility, explores the use of Neighbor Discovery for the discovery of sink nodes and subsequent node registration and, last but not least, allows soft hand-off. The proposed approach has been implemented in a laboratorial environment in order to assess its feasibility and to identify potential problems. In addition to proving the feasibility of the proposal, the tests that were carried out also allowed us to obtain mean hand-off values, which can be used by sensor nodes to estimate the link quality while moving from one sink node to another.
Future work will address three important aspects: further exploration and refinement of the soft hand-off technique; study of the impact of and solutions for movement to successive foreign networks; and study and implementation of route optimization techniques.

5. References

G. Mulligan et al. 'The 6lowpan website'. Available: www.ietf.org/html.charters/6lowpan-charter.html.

K. Dantu, M. Rahimi, H. Shah, S. Babel, A. Dhariwal, and G. Sukhatme, "Robomote: enabling mobility in sensor networks," April 2005, pp. 404Ð409.

A. Labrinidis and A. Stefanidis, "Panel on mobility in sensor networks," in MDM Õ05: Proceedings of the 6th international conference on Mobile data management. New York, NY, USA: ACM, 2005, pp. 333-334.

P. Raviraj, H. Sharif, M. Hempel, H. H. Ali, and J. Youn, "A new mac approach for mobile wireless sensor networks," in Proceedings of the 14th IST Mobile and Wireless Communication Summit, 2005.

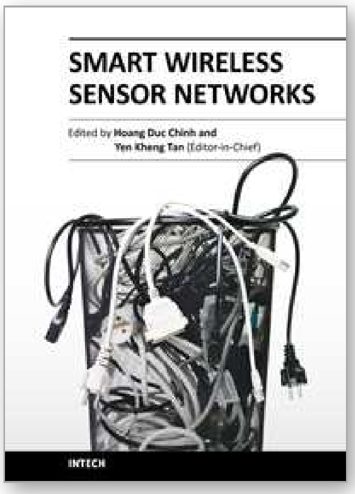
E. Ekici, Y. Gu, and D. Bozdag, "Mobility-based communication in wireless sensor networks," Communications Magazine, IEEE, vol. 44, no. 7, pp. 56-62, July 2006.

W. Ye, J. Heidemann, and D. Estrin, "An energy-efficient mac protocol for wireless sensor networks," vol. 3, 2002, pp. 1567-1576 vol.3.

R. Silva, J. S. Silva, C. Geyer, L. da Silva, and F. Boavida, "Wireless sensor networks - service discovery and mobility," in 7th International Information and Telecommunication Technologies Symposium, Foz do Iguau, BRAZIL, 2008.

R. Silva, J. S. Silva, M. Simek, and F. Boavida, "A new approach for multi-sink environments in wsns," 11th IFIP/IEEE International Symposium on Integrated Network Management, Jun. 2009.

M. Harvan, "Connecting wireless sensor networks to the internet a 6lowpan implementation for tinyos 2.0," presented at the Jacobs University Bremen, Germany, 2007.



Smart Wireless Sensor Networks
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The recent development of communication and sensor technology results in the growth of a new attractive and challenging area â€“ wireless sensor networks (WSNs). A wireless sensor network which consists of a large number of sensor nodes is deployed in environmental fields to serve various applications. Facilitated with the ability of wireless communication and intelligent computation, these nodes become smart sensors which do not only perceive ambient physical parameters but also be able to process information, cooperate with each other and self-organize into the network. These new features assist the sensor nodes as well as the network to operate more efficiently in terms of both data acquisition and energy consumption. Special purposes of the applications require design and operation of WSNs different from conventional networks such as the internet. The network design must take into account of the objectives of specific applications. The nature of deployed environment must be considered. The limited of sensor nodesâ€™ resources such as memory, computational ability, communication bandwidth and energy source are the challenges in network design. A smart wireless sensor network must be able to deal with these constraints as well as to guarantee the connectivity, coverage, reliability and security of networkâ€™s operation for a maximized lifetime. This book discusses various aspects of designing such smart wireless sensor networks. Main topics includes: design methodologies, network protocols and algorithms, quality of service management, coverage optimization, time synchronization and security techniques for sensor networks.

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