System Design and Networking Protocols for Wireless Positioning

B. Peng, A. H. Kemp and W. Ochieng *

Abstract—**The recent boom in wireless communications has led to a wide range of new applications. Wireless positioning is an emerging technology which can provide accurate locations for indoor environments when satellite based positioning systems are not available. In this paper, a Session Initiation Protocol (SIP) based system architecture for wireless positioning is described and an overview of how this can be used in overall system design is provided. New simulation results show that SIP is effective as a network signaling protocol for indoor wireless positioning.**

Keywords: system design, protocols, positioning, wireless networks

1 Introduction

Research on Wireless Sensor Networks (WSNs) as a generic platform holding the promise of many attractive applications such as environmental monitoring, control and target tracking, has been developing rapidly for several years. Notably, knowing the position of network sensors is essential to many applications. Naturally, the huge population of sensors provides a powerful platform for positioning which can enhance the indoor performance when satellite based positioning systems are not available. A logical solution is to use existing and deployed technology at the physical layer to recover ranging information and have this information passed up to the application layer for positioning. A protocol to define the passage of this information at the application layer is necessary and would most conveniently use an existing application layer messaging protocol. Although extensive work has been done in the area of wireless positioning [1, 2, 3, 4], little consideration has been given to a practical architecture which can be actually deployed in the current infrastructure for indoor positioning. In this paper, a Session Initiation Protocol (SIP) based system architecture and network signalling protocol for wireless positioning technology is proposed, its working ability and performance are then evaluated by means of simulation. In this work, we focus on the communication and network protocols which are responsible for delivering the ranging and location information in a sensor network positioning system. Therefore, it is assumed that the ranging information has been calculated by a positioning method in the lower layer. Since our system is based on a centralized approach, there is a location server running a positioning algorithm to calculate the locations of each node and store them for future queries.

The rest of this paper is organized as follows: in Section 2, we specify the requirements for wireless positioning systems. Regarding the satisfaction of SIP with these requirements, section 3 contains both the proposed system architecture and the signaling protocols. Then, the extensive simulations are given to validate the proposal in section 4. The simulation results confirm the working ability of the proposed system and protocols which can satisfy the requirements of wireless positioning according to the service requirement document. Finally, section 5 concludes the paper and gives possible directions for future work.

2 System Requirements

From a system point of view, indoor positioning should be operable seamlessly over many wireless technologies, such as UMTS, WLAN, and Bluetooth. The delay bound is required to reflect the up-to-date knowledge of the location. Inevitably, it must tolerate some degree to interference. Therefore, the following parameters must be specified:

- **Latency**: The time between a request for the position of a mobile device and the response to the query.
- **Update rate**: The update rate is the frequency of position calculation and distribution.
- **Synchronicity and timing**: All ranging measurements must be synchronous over the system to avoid errors in the position estimation.
- **Accuracy and confidence level [5]**: These are key requirements of a wireless positioning system, and relate to the outcome of a geodetic network positioning strategy.

*B.Peng and A.H.Kemp are with the School of Electronic and Electrical Engineering, University of Leeds, LS2 9JT, UK E-mail: {b.peng, a.h.kemp}@leeds.ac.uk. W.Ochieng is with Centre for Transport Studies, Department of Civil and Environmental Engineering, Imperial College London, SW7 2AZ, UK. Manuscript received 08 Feb. 2007; accepted 10 Mar. 2007. The research is funded by EPSRC.

3 SIP for Wireless Positioning

The Session Initiation Protocol (SIP) is a recent development of session management with IETF RFC 3261 proposed standard, appearing in 2002 [6]. SIP is a text based HTTP like application control protocol that can establish, modify and terminate multimedia sessions such as VoIP conferences. Characteristics of SIP for wireless positioning can be summed up as follows:

- **Simplicity and timing**: SIP is very lightweight, and can run on devices with limited processing capabilities.
- **Generic**: SIP separates the signaling of sessions from the description of the sessions.
- **Modularity and extensibility**: SIP is designed to be extensible allowing implementations with different features to be compatible.
- **Integration**: SIP can integrate with other IP protocols, allowing wireless positioning systems to have cross-network operations.
- **Scalability and robustness**: As SIP is an application layer protocol and independent from lower layers, it can operate in small networks (piconet), larger networks (scatternet, LAN, PAN) or large geo-scale networks (MAN or worldwide scale).

Regarding the specified system requirements of wireless positioning [7], SIP is effective as a network signaling protocol for wireless positioning.

3.1 System Design

The proposed SIP architecture for Wireless Positioning is based on SIP Mobility Management for Wireless Communication. Figure 1 shows a basic SIP system architecture for Wireless Positioning, which consists of a SIP gateway, proxy server, redirect server, registrar server and location server [8]. The information of the SIP user, device's ID, access ports, and other ranging information (which is obtained from the ranging process to nearby devices) and related time stamp are conveyed to the registrar server by using the REGISTER method. This information is to be processed by the positioning software on the location server. Including known positions of nearby anchor nodes, it is possible for the positioning application to identify the coordinate position and accuracy of each registered device. The device's position and other related information such as quality indicators are then stored on the location database of the location server. The registration temporarily binds a user's Uniform Resource Identifier (URI) with a Contact URI of a particular device. Such a contact URI field in the SIP header should also contain other ranging information. The user can move

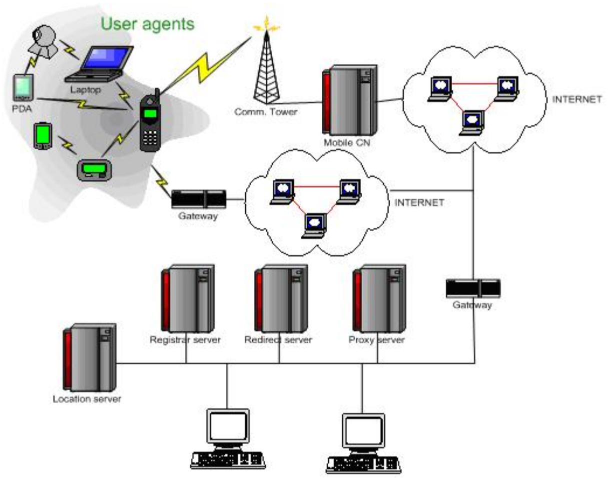

Figure 1: SIP system architecture for Positioning

between the service providers and use multiple layer registrations. The contact URI field can contain timing related information described in the specification requirements, such as an expire parameter, which indicates how long the contact information is valid. In order to establish a common time reference and identify the latency and validity of information messages, a time tag is also included in the header fields.

When the SIP user agent would like to query location information or other information of a user agent, it could use the OPTIONS method. The OPTIONS request is generated by the user agent and when the server receives the query with a callee's user agent ID, such as SIP URI, time valid, it will look at the location database on the location server to find the position information of the callee. Otherwise it will forward the request to the callee. The server or callee sends back to the caller the response message in the same way as it would do to an INVITE request. The success 2xx class response (e.g. 200 OK message) contains the position information of the callee, including the time tag of the last position update, SIP address, device ID, position coordinate, and accuracy level.

3.2 Protocol Design

As SIP is a text based HTML like application control protocol, it is not as complicated for compiling and processing as other lower layer protocols. There are several methods to embed information including device location information on SIP messages. However from the point of view that Wireless Positioning is an extension of Wireless Mobility Management, the SIP protocol for Wireless Positioning could be based on current SIP messages for Mobility Management with some modifications. Two basic SIP request messages proposed for Wireless Positioning are: REGISTER and OPTIONS. Including those two requests, the SIP response messages still follow IETF RFC SIP definitions with some modifications. Figure 2

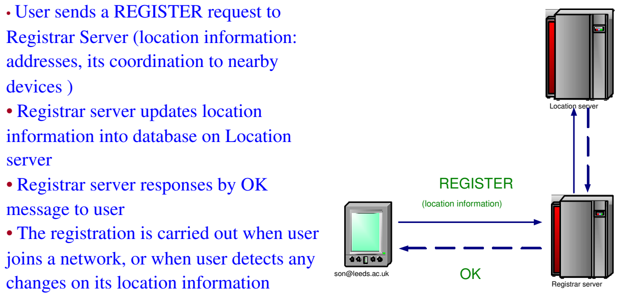

Figure 2: An example of SIP Registration for positioning

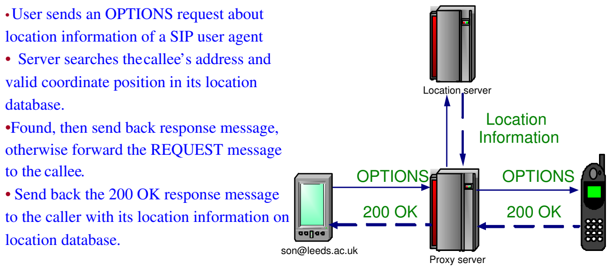

Figure 3: An example of SIP Notification for positioning

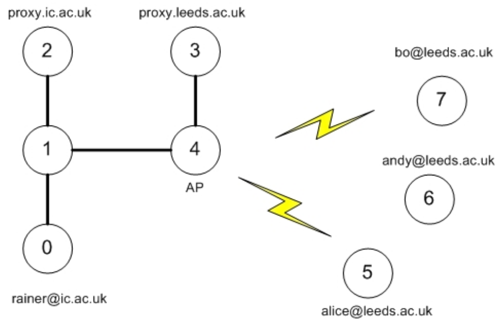

Figure 4: Simulation Scenario 1

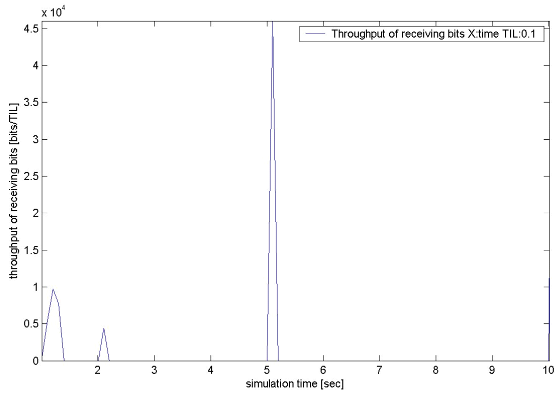

Figure 5: Average throughput of receiving bits

and Figure 3 are the examples of SIP Registration and Notification for positioning respectively.

4 Performance Evaluation

In this section, we present the performance evaluation of our proposed scenarios by means of simulation in Network Simulator 2 (NS-2). Regarding the requirements of the wireless positioning system, we evaluate the working ability and the overall performance of our proposed SIP protocols for wireless positioning, especially in terms of latency bound and network traffic load of SIP signalling messages. Simulation results confirm that our proposed system is able to meet the service requirements described in the Service Requirements Document [9].

4.1 Simulation Model

The network area is arbitrarily assumed to be a 670m by 670m region. There are five wired nodes and many mobile user agents connected to the wired domain via an Access Point (AP). The model includes two wired domains, arbitrarily called IC and Leeds. Two proxy servers in each domain are at node 2 and node 3. We also combine the function of register server and location server on node 2 and node 3. Therefore, all the registration and location information will be processed on node 2 and node 3 in each domain respectively. The duplex link bandwidth between wired nodes is conservatively set to 5Mbps. IEEE 802.11 is used as the MAC protocol and Destination-Sequenced Distance-Vector (DSDV) Routing as the routing protocol. We assume that all transmissions over the wireless channel do not exceed the receiving threshold. That means the power level at which the packet was received at the MAC layer is above the threshold, in this case, no packet is discarded as noise or marked as a packet in error, all packets are simply handed up to the MAC layer successfully. Simulation only records the SIP signalling messages for analysis.

4.2 Scenario 1

Figure 4 shows the first simulation scenario proposed. In this scenario, only three nodes are included and the main purpose is to validate the working ability of the proposed protocol, and evaluate the throughput and end-to-end delay during the registration and notification process which may introduce extra traffic load on the existing network infrastructures.

Figure 5 shows the average throughput of received bits. The SIP registration messages are generated at the time of the simulation starts and at 2.0s when all the three mobile users (Bo, Andy and Alice) and one fixed user (Rainer) register themselves on proxy.leeds.ac.uk and proxy.ic.ac.uk respectively. The throughput during this registration process introduces up to 10kbps traffic load on the network. After all the registration is done, there

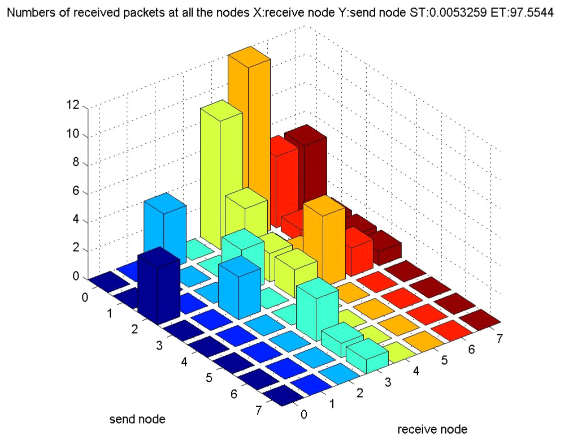

Figure 6: Number of received packets at all the nodes

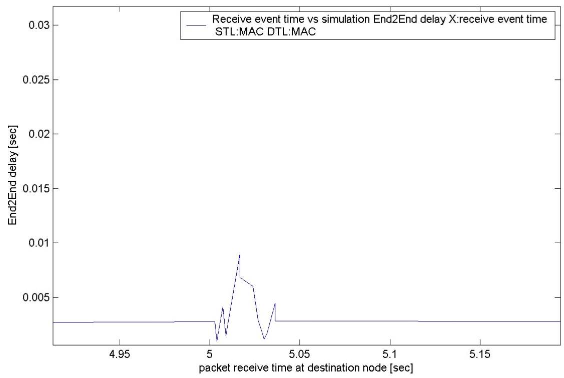

Figure 7: Average End-to-End delay during notification process

is no other signalling message between 2.2 and $5s$. At $5s$, the user Rainer request the location information from Alice using the proposed Notification Process. This process introduces higher traffic load as showed in Figure 5, up to $46kbps$, but for a short time duration. Therefore, this will not introduce significant traffic overhead on existing network if the number of simultaneous requests are in the normal range. Finally, at $10s$, the SIP signalling message will be generated by Rainer to end the session with Alice. The average throughput of this process is $11kbps$. Figure 6 shows a overall view of the number of sending and received packets at all the nodes.

Figure 7 and 8 illustrate the average end-to-end delay between all sending nodes and receiving nodes without considering the wireless links. In general, the delay of SIP signalling message, $5ms$ which satisfies the delay re-

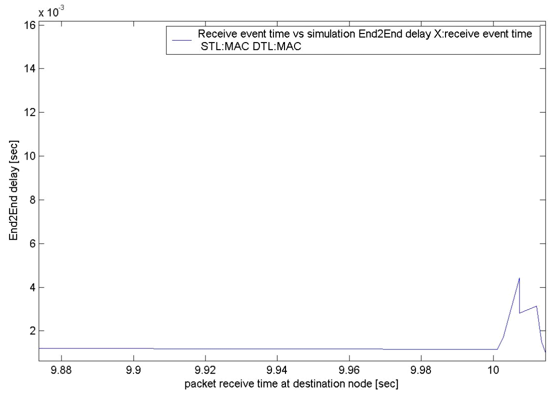

Figure 8: Average End-to-End delay during terminating the session

quirements in SRD [9]. Although during the registration, notification and ending process, there are some delay variations (up to $10ms$), they are all still in the accepted range for the position purpose. Therefore, the results validate the working ability of proposed protocol in terms of latency bound.

4.3 Scenario 2

In this section, another scenario of continuous tracking of a node is evaluated. It requires using the REGISTRATION method to update the ranging information periodically to detect if there is any node moving. The update period used in this simulation is $1s$ (which is very high according to the positioning requirements in [9]) and all nodes will send back the updated messages simultaneously back to registration server.

Figure 9 shows the average throughput of receiving bits of different numbers of mobile agents. The throughput increases gradually by increasing the number of nodes. At the beginning of simulation, the throughput increases rapidly and reachs the peak at $2s$, and then decrease a little and stays at the same level until the end of the simulation. This indicates that increasing the number of mobile nodes will increase the traffic load over the whole network gradually. When the mobile node number is 20, traffic will reach about $200kbps$, which will introduce high traffic load on the network. So, if the number of nodes is high, the update rate should be made as infrequent as possible to achieve scalability (it can be reduced to $10s$ see [9]). Figure 10 shows the average end to end delay with different number of mobile nodes. In general, the delay increases with increasing number of mobile nodes. Since all the update messages are generated at the same time, the delay jumps up at each update second and drops back until the next update second. Table 1 gives a summary by comparing the information of different numbers of mobile

ISBN:978-988-98671-2-6

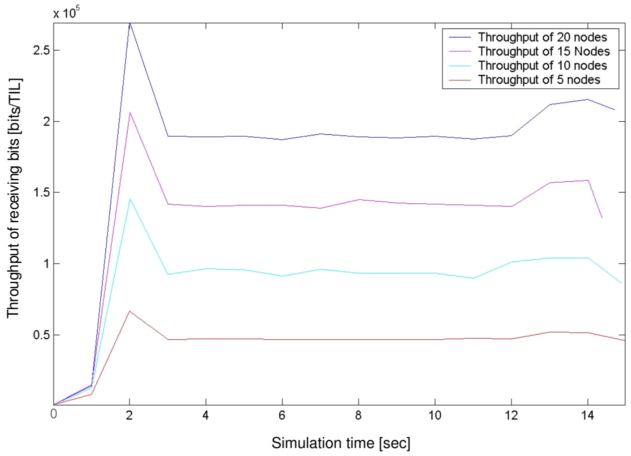

Figure 9: Average throughput of receiving bits with different number of mobile nodes

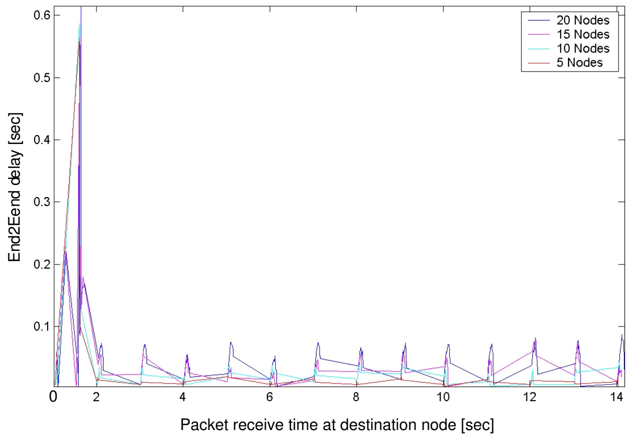

Figure 10: Average end to end delay with different number of mobile nodes

Number of nodes	10	15	20	25
Simulation length in seconds	14	14	14	14
Number of generated packets	692	1411	2113	2871
Number of forwarded packets	237	472	700	951
Number of dropped packets	4	27	77	310
Minimal packet size	28	28	28	28
Maximal packet size	372	372	372	372
Average packet size	128	123	118	112

Table 1: Summary of simulation information with different number of nodes

nodes.

4.4 Scenario 3

In previous sections, all user agents (nodes) were assumed stationary and within the radio range of the AP. That meant all the signalling messages were only exchanged between user agents and AP directly, namely, one hop communication only. In this section, multi-hop communications between the mobile nodes and AP will be introduced. All nodes can act not only as the sources of information but also as the relay nodes to pass the message for other source nodes which are out of the AP radio range. In this scenario, a node chooses its speed and its destination randomly, moves to the destination, then pauses for a while, and so on. Since the impact of mobility is a very complex issue to address and also out of scope of this paper, we select the most common movement parameters, as follows, for our evaluation. However, the simulator is still available for users to specify their own parameters. All mobile nodes move randomly in a 670 by 670m area at a normal speed between 1 m/s and 3 m/s and with a constant pause time of 1 second. The AP and all mobile nodes have the same transmission range of 250m. DSDV is used as the routing protocol to route the message generated by source nodes which are probably out of the radio range of AP to AP by intermediate relay nodes. The same REGISTRATION method in scenario 2 is evaluated in terms of traffic load. All simulations run for 100s and the results are the average of repeating each simulation 50 times.

Figure 11 shows the throughput of SIP register messages of a different number of mobile nodes at the update rate of $1/s$. Generally, the throughput increases gradually by increasing the number of nodes. This indicates that the increasing of the density of the mobile nodes will increase the traffic load over the whole network gradually. Besides the obvious reason that more traffic sources generate more traffic, a high density of network nodes is also helpful to increase the chance of successful transmission from source nodes to the AP because of the high number of available relay nodes. When the mobile node number is 20, the traffic is up to $1.1Mbps$, which introduces a much higher traffic load than scenario 2 (where it is up to $200Kbps$). This confirms our expectation that the multi-hop transmissions will introduce higher traffic load on the existing network infrastructure.

Figure 12 shows the throughput of SIP register messages for different update rates with 15 mobile nodes. Three different update rates, $1s$, $3s$ and $6s$, are compared. As we can see in Figure 12, a more frequent update rate introduces more traffic load. For the most frequent update rate of $1s$, the traffic load is up to $950Kbps$. However, regarding the requirement in [9], the update rate can be reduced to $10s$ which is still acceptable for most positioning applications. Therefore, in terms of the scalability, the performances of the proposed system meets the

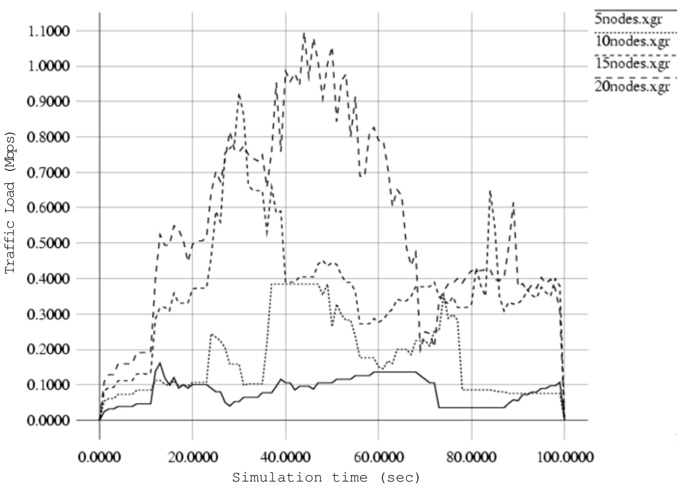

Figure 11: SIP Register message load of different number of nodes at the update rate for 1 sec

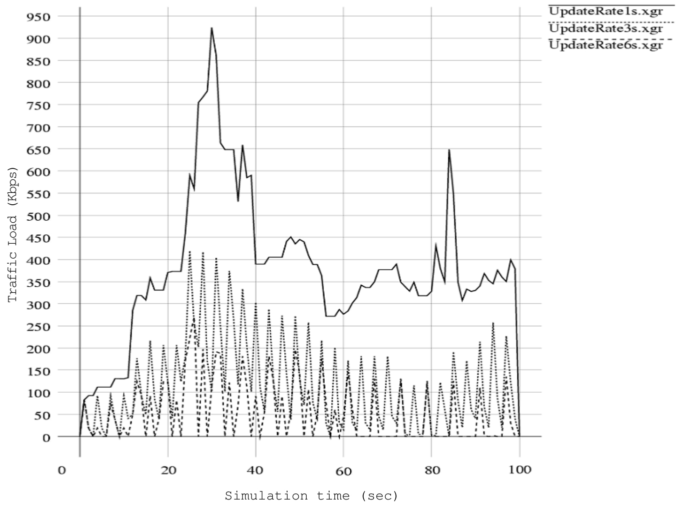

Figure 12: SIP Register message load in different update rate with 15 mobile nodes

targets in SRD [9].

5 Conclusions

Wireless Positioning for mobile devices is a relatively new field, in which wireless communication, Internet, and navigation, are combined and the proposed SIP based wireless positioning system and protocols have opened many new research issues, from the physical layer, link layer and higher application layer. As the history of Internet based SIP is short and has just been specified in 3GPP for UMTS release 6, the protocol specification for other wireless technologies, e.g Bluetooth, ZigBee, WLAN 802.1x, etc., should follow. In this paper, a SIP based system for wireless positioning has been designed and the overall performance has been evaluated in terms of traffic load of the signalling messages. The simulation results confirm that the working ability of the proposed system and protocols can satisfy the requirements of wireless positioning according to service requirement document [9]. Notably, the proposed SIP wireless positioning protocol could be enhanced to improve performance, especially for overload situations, or handoff scenarios. Further work will address the impact of the mobile profile (e.g. end-to-end delay of moving nodes from one domain into another domain) which will also affect the performance of our system. These open issues require more research and bring many new challenges.

References

[1] D. Niculescu and Nath, "Ad-hoc positioning system," in *IEEE GlobeCom*, 2001.

[2] C. Savarese, K. Langendoen, and Rabaey, "Robust positioning algorithms for distributed ad-hoc wireless sensor networks," in *USENIX Technical Annual Conference*, Monterey, CA, 2002, pp. 317–328.

[3] A. Savvides, H. Park, and M. Srivastava, "The n-hop multilateration primitive for node localization problems," in *MONET 8(4)*, pp. 443–451.

[4] A. Smith, H. Balakrishnan, M. Goraczko, and P. N, "Tracking moving devices with the cricket location system," in *Proc. 2nd USENIX/ACM MOBISYS Conf*, Boston, MA, June 2004.

[5] R. Mautz, W. Ochieng, G. Brodin, A. H. Kemp, and B. Peng, "Reliable positioning in wireless sensor networks," in *European Navigation Conference*, Manchester, 8 - 10 May 2006.

[6] J. Rosenberg, H. Schulzrinne, G. Camarillo, A. Johnston, J. Peterson, R. Sparks, M. Handley, and E. Schooler, "SIP: Session initiation protocol," in *RFC 3261*, June 2002.

[7] R. Mautz, W. Ochieng, D. Walsh, G. Brodin, J. Cooper, A. Kemp, and T. Le, "Low-cost intelligent pervasive location and tracking (iplot) for the management of crime," *Journal of Navigation*, vol. 59, 2006.

[8] B.Peng, A.H.Kemp, G.Brodin, R. Mautz, and W. Ochieng, "SIP for wireless positioning: System and architecture," in *Joint IST Workshop on Sensor Networks & Symposium on Trends in Communications (SympoTIC' 06)*, Bratislava, SLOVAKIA, June 2006.

[9] R. Mautz, W. Ochieng, and D. Walsh, "Intelligent pervasive location tracking (iPLOT)-service requirements document (SRD)," in *Internal report*, 2005.