

WIRELESS SENSOR ACTOR NETWORKS AND ROUTING PERFORMANCE ANALYSIS

Dung Van Dinh¹, Minh Duong Vuong², Hung Phu Nguyen³, Hoa Xuan Nguyen⁴

^(1,2) *Research Institute of Posts and Telecoms (RIPT)*, adlien@hn.vnn.vn,

⁽³⁾ *Post and Telecommunications Institute of Technology (PTIT)*, ⁽⁴⁾ *Hanoi University of Technology (HUT)*

Abstract - With recent advances in micro-electro-mechanical systems technology, wireless communications, and digital electronics, the research on wireless sensor networks becomes a “hot” topic. Wireless sensor and actor network (WSAN) is referred to a group of sensors and actors linked by wireless medium to perform sensing and acting tasks. This paper is to present a comprehensive review of recent research achievements on WSANs, open research issues, and the simulation based actor-to-actor routing protocols performance analysis. The review is followed the layers of sensor networks: application, transport, network, link, transmission, and management (power, mobility, task). The performance analysis is considered for three popular ad-hoc networks routing protocols and investigated with respect to the routing packet delay and end-to-end throughput. As a result, the DSR protocol is proposed to handle actor-to-actor communications.

Keywords – Sensor Network, SWAN, Routing, Simulation.

I. INTRODUCTION

There are three different research areas on sensor networks: sensing, communication, and computing (including hardware, software, and algorithms). Examples of early sensor networks include the radar networks used in air traffic control. The national power grid, with its many sensors, can be viewed as one large sensor network. These systems were developed with specialized computers and communication capabilities, and before the term “sensor networks” was coined [1]

Applications have been a driver for research and development in sensor networks. During the Cold War, the Sound Surveillance System (SOSUS), a system of acoustic sensors on the ocean bottom, was deployed at strategic locations to detect and track quiet Soviet submarines. Over the years, other more sophisticated acoustic networks have been developed for submarine surveillance. SOSUS is now used by the National Oceanographic and Atmospheric Administration (NOAA) for monitoring events in the ocean, e.g., seismic and animal activity. Also during the Cold War, networks of air defence radars were developed and deployed to defend the continental United States and Canada. This air defence system has evolved over the years to include aerostats as sensors and Airborne Warning and Control System (AWACS) planes, and is also used for drug interdiction.

Modern research on sensor networks started around 1980 with the Distributed Sensor Networks (DSN) program at the Defence Advanced Research Projects Agency (DARPA). Technology components for a DSN were identified in a Distributed Sensor Nets workshop in 1978. These included sensors (acoustic), communication (high-level protocols that link processes working on a common application in a resource-sharing network), processing techniques and algorithms (including self-location algorithms for sensors), and distributed software (dynamically modifiable distributed systems and language design). Since DARPA was sponsoring much artificial intelligence (AI) research at the time, the workshop also included talks on the use of AI for understanding signals and assessing situations, as well as various distributed problem-solving techniques.

Researchers at Carnegie Mellon University (CMU), Pittsburgh, PA, focused on providing a network operating system that allows flexible, transparent access to distributed resources needed for a fault-tolerant DSN. Researchers at the Massachusetts Institute of Technology (MIT), Cambridge, focused on knowledge-based signal processing techniques for tracking helicopters using a distributed array of acoustic microphones by means of signal abstractions and matching techniques. In addition, MIT also developed the Signal Processing Language and Interactive Computing Environment (SPLICE) for DSN data analysis and algorithm development, and Pitch Director’s Assistant for interactively estimating fundamental frequency using domain knowledge. That was the state of the art in the early 1980s. The DSN test bed was demonstrated with low-flying aircraft, which was successfully tracked with acoustic sensors as well as TV cameras. The tracking algorithm was fairly sophisticated, since the acoustic propagation delay is significant relative to the speed of the aircraft. Another test bed in the DSN program was the distributed vehicle monitoring test bed at the University of Massachusetts, Amherst.

Recent advances in computing and communication have caused a significant shift in sensor network research and brought it closer to achieving the original vision. Small and inexpensive sensors based upon micro-electromechanical system (MEMS) [2] technology, wireless networking, and inexpensive low-power processors allow the deployment of wireless ad hoc networks for various applications. Again, DARPA started a research program on sensor networks to leverage the latest technological advances. The recently concluded DARPA Sensor Information Technology (SensIT) program pursued two key research and development thrusts. First, it developed new networking techniques. The second thrust was networked information

processing, i.e., how to extract useful, reliable, and timely information from the deployed sensor network.

Recent technological advances have led to the emergence of distributed wireless sensor and actor networks which are capable of observing the physical world, processing the data, making decisions based on the observations and performing appropriate actions. These networks can be an integral part of systems such as battlefield surveillance and microclimate control in buildings, nuclear, biological and chemical attack detection [3], home automation [4] and environmental monitoring. WSNs have the unique characteristics: real-time requirement and coordination. Many protocols and algorithms have been proposed for Wireless Sensor Networks (WSNs) in recent years. However, since the above listed requirements impose stricter constraints, they may not be well-suited for the unique features and application requirements of WSNs. Moreover, although there has been some research effort related to WSNs, to the best of our knowledge, none of the existing studies to date investigate research challenges occurring due to the coexistence of sensors and actors.

For example, both in [5] and [6] control engineering problems and existing technologies about sensor and actor networks are presented, respectively. However, neither of these studies investigates the interaction among sensors and actors. In [7], only actor-actor coordination is handled without any insight into the sensor-actor coordination problem. A TDMA MAC protocol is also introduced in [8] where it is assumed that sensor and actor nodes are of same type which obviously does not reflect the actual WSNs. In [9], the routing problems are investigated between sensor and actor nodes. However, no coordination problems in sensor-actor or in actor-actor communications are considered in the study.

Despite some existing research in WSN, there are many problems that arise in WSNs due to the coexistence of sensors and actors have to be investigated. This paper is to present a WSN physical architecture (Section II), a comprehensive review of recent proposals, open research issues (Section III), and a simulation based actor-to-actor routing performance analysis (Section IV).

II. WSN ARCHITECTURE

In this section, an overview of WSN given in [11] is presented. Sensor and actor nodes are to collect data from the environment and perform appropriate actions based on this collected data, respectively. As shown in Figure 1 these nodes are distributed in the sensor/actor field while the sink monitors the overall network and communicates with the task manager node and sensor/actor nodes.

Sensor nodes detecting a phenomenon either transmit their readings to the actor nodes which process all incoming data and initiate appropriate actions, or route data back to the sink which may send commands to actors. The former case is named as Automated Architecture due to the non-existence of central controller, e.g., human interaction, while

the latter case is defined as Semi-Automated Architecture since the sink (central controller) collects data and coordinates the acting process. The advantage of the Semi-Automated Architecture is that it is similar to the architecture already used in wireless sensor network applications [1]. Thus, this paper is to review recent proposals and research challenges for WSNs rather than for WSNs.

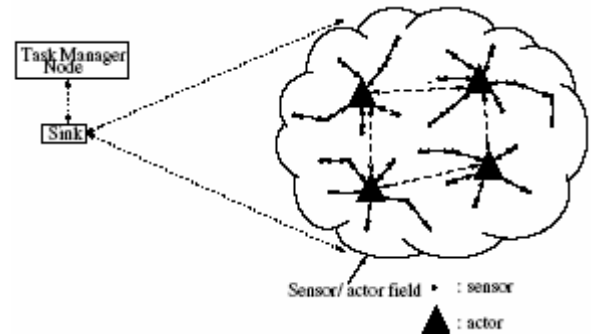


Figure 1. An architecture of WSNs. [11]

Architectures of sensor and actor nodes used in the WSN can be shown as in Figure 2(a) and (b), respectively. Sensor nodes are equipped with power unit, communication subsystems (receiver and transmitter), storage and processing resources, Analog to Digital Converter (ADC) and sensing unit, as shown in Figure 2(a). The sensing unit observes phenomena such as thermal, optic or acoustic event. The collected analog data are converted to digital data by ADC and then are analyzed by a processor and then transmitted to nearby actors.

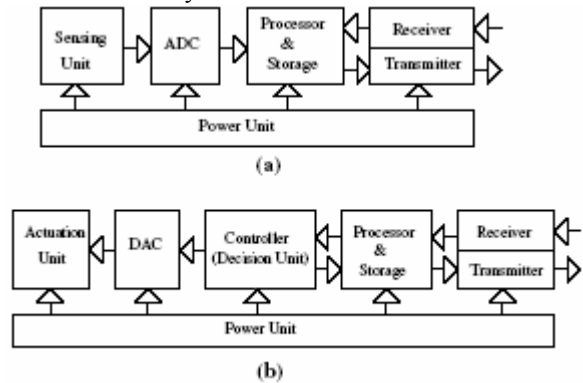


Figure 2. (a) sensor and (b) actor nodes architectures. [11] The decision unit (controller) takes sensor readings as input and generates action commands as output. These action commands are then converted to analog signals by the Digital to Analog Converter (DAC) and are transformed into actions via the actuation units.

In some applications, integrated sensor/actor nodes may replace actor nodes. Since an integrated sensor/actor node is capable of both sensing and acting, it has sensing unit and ADC in addition to all components of an actor node.

In most situations actor-actor communication is also required to achieve the overall application objective in WSNs. Since actors are resource-rich nodes with high

transmission power, actor-actor communication can be long-range unlike sensor-actor communication. Furthermore, actor-actor communication is similar to the communication paradigm of ad-hoc networks due to the small number of (mobile) resource-rich actor nodes being loosely deployed. Therefore, WSAN can be considered as the union of wireless sensor and ad-hoc networks. In addition to both sensor and ad-hoc network challenges, there exist challenges due to the real-time properties and nature of “acting” phenomenon.

III. RESEARCH CHALLENGES

A. Sensor-actor coordination

In WSANs, multiple actors can receive the information from sensors about the sensed phenomenon and this case is denoted as Multi-Actor (MA). Unlike this situation where sensor readings are sent to multiple actors, only one actor receives event features, this case is denoted as Single-Actor (SA). In fact, SA can be considered as a special case of MA. The following research issues related to SA and MA cases can be concluded for sensor-actor coordination in WSANs [11]:

- To ensure that there are no adverse effects on the target environment.
- To ensure synchronization in the reporting time of the sensed phenomena between different actors.
- In MA, it is necessary to send the information only to a subset of actors which cover the entire event region.
- The advantages and disadvantages of both SA and MA need to be analytically investigated to figure out which one is appropriate for given applications or situations.

B. Coordination among actors

In WSANs, actors communicate with each other in addition to communicating with sensors. Actors coordinate explicitly and with purpose either in centralized way or in distributed way in order to solve the task assignment problems in WSANs. This coordination has the following challenges [11]:

- In a single-actor task case, the problem is how to select the single actor among all capable actors and how to find an optimum number of actors performing the actions in a multi-actor task case.
- A communication model between actors.
- Execution of different events detected in a region may be required to ensure that there are no adverse effects on the target environment.
- Some applications may require synchronization of actors to act on the event at the same time.
- There is a need to specify the contents of messages and algorithms which provide efficient data transmission for different types of messages.
- How to select an actor which will function as a decision unit.
- Coordination and communication protocols should support real-time properties of WSANs.

C. Transport layer

The new transport protocols must support real-time requirements in WSANs. Several transport layer protocols have been developed for ad-hoc networks and wireless sensor networks in recent years [1][12][13]. However, there exist no transport protocols which deal with both the reliability and real-time for WSANs to date. Since sensor-actor and actor-actor communications occur consecutively in WSANs, a unified transport protocol is required for both cases.

D. Routing layer

In WSANs, when sensors detect an event, there is no specific actor to which a message will be sent. This uncertainty occurring due to the existence of multiple actors causes challenges in terms of routing solutions. Selecting an actor node is one of the challenges for a source sensor node. In addition to determining the path selection and data delivery, routing protocol should support real-time communication by considering different deadlines due to different validity intervals. Moreover, the routing protocol should also consider the issue of prioritization and should provide data with low delay bounds to reach the actor on time.

In recent years there has been a considerable amount of research on routing problems in sensor networks [9]. An anycast mechanism developed in [10] does not support the sensor-sensor coordination occurring in WSANs due to the result of correlated information among multiple sensor sources which detect the same event. Moreover, this mechanism causes a sensor which is one hop away from an actor to receive also interests from an actor on the other side of the network. This may cause unnecessary traffic load in the network. SEAD developed in [14] is also not suitable for WSANs since it does not deal with end-to-end delay minimization which is one of the main goals in WSANs. Furthermore, it is developed for the case where all sinks request data from one source at refresh rates, whereas in WSANs only actors which are in the vicinity of a phenomenon are interested in the event information.

SPEED [15] is an adaptive, location-based real-time routing protocol which can be effectively used if the location information is available in all sensor nodes and the location updates can be delivered to the source sensors regularly. However, SPEED is not suitable for WSANs since it does not support Multi-Actor (MA) case and the mobility of actors.

Moreover, a model with resource-limited sensor nodes and higher energy capacity cluster heads is given in [16]. This model may be suitable for WSANs such as an actor can become a cluster head and each source sensor can become a member of a cluster.

However, several open research issues must be investigated such as

- How are the clusters formed, e.g., are they formed based on the event?
- How will the clusters be adaptive to mobility, or

- How will the clusters satisfy the real-time constraints?
For actor-actor communication, routing protocols developed for ad-hoc networks such as DSR, AODV, OLSR [17] can be used as long as they are improved so that real-time requirements are met and communication overhead occurring at sensor nodes due to actor-actor communication is low.

E. Medium access control

In order to effectively transmit the event information from large number of sensors to actors there is a need for MAC protocol. Moreover, in some applications, (i.e., distributed robotics) actors may be mobile. As they move, they may leave the transmission regions of some sensors and enter other sensors region or they may become totally disconnected from the network. Therefore, another function of MAC protocol in WSNs is to maintain network connectivity between sensors and mobile actors. Furthermore, as discussed before, the timely detection, processing, and delivery of information are indispensable requirements in a sensor/actor network application.

Classical contention-based protocols are not appropriate for real-time sensor-actor communication since contention-based channel access requires handshaking which increases the latency of the data. TRACE [18] is a reservation TDMA protocol which suffers from the added overhead for reservation contention while PBP (Predictive Backoff Protocol for IEEE 802.11) suffers from the requirement of large amount of energy due to all sensors listening to others' transmissions.

By exploiting the periodic nature of the sensor network traffic, a collision-free real-time scheduling algorithm is presented in [19]. Collision-free protocols may be suitable for WSNs, because they can potentially reduce the delay and provide real-time guarantees as well as save power by eliminating collisions. A problem in a large class of current collision-free protocols is the use of multiple channels [19]. This imposes a nontrivial requirement on the hardware of the nodes in the network as mentioned in [20]. Thus, further study is needed to tell whether the performance gain would overcome the increased cost of the hardware. Moreover, in [19] and generally in all existing collision-free protocols the mobility is not investigated.

For actor-actor communication, the existing MAC protocols developed for ad-hoc networks cannot be directly used. They should be improved so that they support real-time traffic, since in WSNs, depending on the application, interaction with the world may impose a real-time constraint on computation and communication.

F. Cross-layering

Current WSN and WSN protocol designs are largely based on a layered approach. However, the sub-optimality and inflexibility of this paradigm result in poor performance for WSNs, due to constraints of low energy consumption and low latency. Therefore, instead of having individual layers,

there will be a need of cross-layering where layers are integrated with each other.

G. Products development

There is a large amount of work on developing micro-electromechanical sensors and new communication devices. The development of these new devices make a strong case for the development of a software platform to support and connect them. TinyOS is designed to fill this role [21]. Current real-time operating systems do not meet the needs of the emerging integrated regime. Many of them have followed the performance growth of the wallet size device. Traditional real time embedded operating systems include VxWorks, WinCE, PalmOS, and QNX and many others.

A major architectural question in the design of network sensors is whether or not individual microcontrollers should be used to manage each I/O device. It is possible to maintain multiple flows of data with a single microcontroller. This shows that it is an architectural option - not a requirement - to utilize individual microcontrollers per device. Moreover, the interconnect of such a system will need to support an efficient event based communication model. Tradeoffs quickly arise between power consumption, speed of off chip communication, flexibility and functionality [21].

IV. WSN ROUTING PERFORMANCE ANALYSIS

There is a number of simulation platforms for Ad-hoc/Sensor networks including SWAN (Dartmouth & BBN [22]), SensorSim (UCLA [23]), H-MAS (Notre Dame [24]), Naval [25], and Rice Monarch [26]. In this paper, the actor-to-actor routing performance analysis is based on the NS-2 framework [27] with the software extensions of Naval and Rice Monarch. The readers who are interested in simulation models and software platform, are recommended to find at [25][26][27].

This study provides a realistic, quantitative analysis comparing the performance of a variety of multi-hop wireless routing protocols when applied to actor-to-actor communications in Wireless sensor and actor networks. It shows the relative performance of three proposed routing protocols for WSNs: DSDV [28], AODV [29][30], and DSR [31][32][33]. The DSDV (Destination Sequenced Distance Vector) protocol is a hop-by-hop distance vector routing protocol requiring each node to periodically broadcast routing updates. The key advantage of DSDV over traditional distance vector protocols is that it guarantees loop-freedom. DSR (Dynamic Source Routing) protocol is based on source routing, which means that the originator of each packet determines an ordered list of nodes through which the packet must pass while traveling to the destination. The key advantage of a source routing design is that intermediate nodes do not need to maintain up-to-date routing information in order to route the packets that they forward, since the packet's source has already made all of the routing decisions. This fact, coupled with the entirely on-demand nature of the protocol, eliminates the need for

any type of periodic route advertisement or neighbor detection packets. AODV (Ad Hoc On-Demand Distance Vector) protocol is essentially a combination of both DSR and DSDV. It borrows the basic on-demand mechanism of Route Discovery and Route Maintenance from DSR, plus the use of hop-by-hop routing, sequence numbers, and periodic beacons from DSDV [34].

As mentioned in Section III, the routing protocols used in ad-hoc networks may be applied for WSNs actor-to-actor communications. These protocols are evaluated within the sensor manner and simulation results are shown in Figure 3, Figure 4. Despite of higher delay compared to AODV and DSR at the beginning, DSDV has lowest delay level when the network is in a stable state. However, the DSR protocol has highest end-to-end throughput (ratio of packet received /packet sent) compared to DSDV and AODV. Therefore, the DSR protocol is proposed to handle actor-to-actor communications. Although, DSR is the best protocol among the three selected routing candidates, there will be a need of designing a routing protocol that is optimized not only for supporting the sensor-actor and actor-to-actor coordination, but also satisfies the cross-layering constraints. To reach at such global optimization solution, the simulation optimization protocol design approach [35] is proposed to be used.

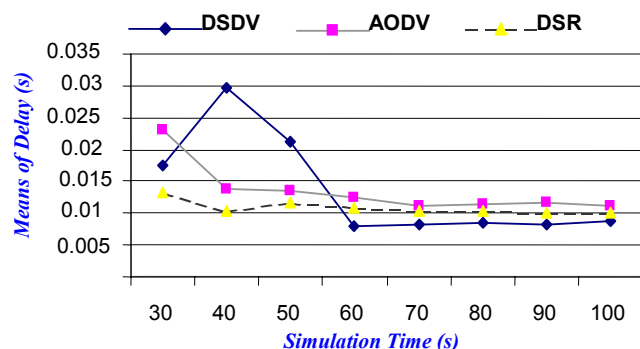


Figure 3. DSDV/AODV/DSR mean of packet delay

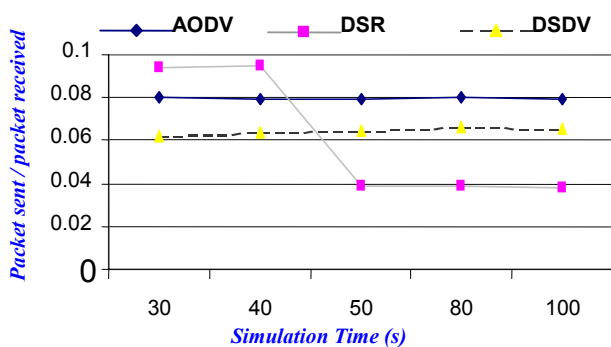


Figure 4. Packet sent/packet received vs. Simulation time

V. CONCLUSIONS

WSAN nodes can be used for continuous sensing, event detection, event identification, location sensing, and local control of actuators. The concept of micro-sensing, wireless connection, self-acting of these nodes shows many new application paradigms. Sensor networks can be applied to military, environment, health, home and other commercial areas. It is possible to expand this classification with more categories such as space exploration, chemical processing and disaster relief.

There are many challenges for WSNs: sensing, communication, and computing (including hardware, software, and algorithms). The following issues are considered as further research problems that should be investigated in WSNs:

- Algorithms providing ordering, synchronization and eliminate the redundancy of actions between sensors and actors.
- A unified framework that can be exploited by different applications to select the best networking paradigm and provide efficient actor-actor communications.
- Open WSN layering architecture
- Effective algorithms for a single layer as well as cross-layering requirements.
- Real-time communication protocols for both sensor-actor and actor-actor coordination in WSNs.
- Low cost and reliable system architecture for networked sensors.

Dealing with routing challenges, the simulation based routing performance analysis has shown that DSR is the best solution for actor-to-actor communications in WSNs among the other ad-hoc routing protocols.

REFERENCES

- [1] Chee-Yee Chong, Srikanta P. Kumar, "Sensor Networks: Evolution, Opportunities, and Challenges," *Proceedings of the IEEE*, Vol. 91, No. 8, August 2003.
- [2] J.W. Gardner, V. K. Varadan, and O. O. Awadelkarim, *Microsensors, MEMS and Smart Devices*. New York: Wiley, 2001.
- [3] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, "Wireless sensor networks: A survey," *Computer Networks* 38 (4) (2002) 393-422.
- [4] E.M. Petriu, N.D. Georganas, D.C. Petriu, D. Makrakis, V.Z. Groza, "Sensor-based information appliances," *IEEE Instrumentation and Measurement Magazine* 3 (4) (2000) 31-35.
- [5] M. Chow, Y. Tipsuwan, "Network-based control systems," in: *Proc. of IEEE IECon 2001 Tutorial*, Denver, CO, November 28-December 2, 2001, pp. 1593-1602.
- [6] M. Haenggi, "Mobile sensor-actuator networks: opportunities and challenges," in: *Proc. 7th IEEE Int. Workshop*, Frankfurt, Germany, July 2002, pp. 283-290.
- [7] B.P. Gerkey, M.J. Mataric, "A market-based formulation of sensor-actuator network coordination," in: *Proc. of the AAAI Spring Symposium on Intelligent Embedded and Distributed Systems*, Palo Alto, CA, March 25-27, 2002, pp. 21-26.

- [8] T.W. Carley, M.A. Ba, R. Barua, D.B. Stewart, "Contention-free periodic message scheduler medium access control in wireless sensor/actuator networks," in: *Proc. of Real-Time Systems Symposium*, Cancun, Mexico, December 2003.
- [9] K. Akkaya, M. Younis, "A survey on routing protocols for wireless sensor networks," *AdHoc Networks*, in press, 10.1016/j.adhoc.2003.09.010.
- [10] W. Hu, N. Bulusu, S. Jha, "An anycast service for hybrid sensor/actuator networks," in: *Proc. of the 15th IEEE Int. Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC)*, Barcelona, Spain, 5–8 September 2004.
- [11] Ian F. Akyildiz, Ismail H. Kasimoglu, "Wireless sensor and actor networks: research challenges," *Ad Hoc Networks (Elsevier)*, Vol. 2, Issue 4, pp. 351-464 (October 2004).
- [12] I. Chlamtac, M. Conti, J.N. Liu, "Mobile ad-hoc networking: imperatives and challenges," *Ad Hoc Networks* 1(1) (2003) 13–64.
- [13] A.J. Goldsmith, S. Wicker, "Design challenges for energy constrained ad-hoc wireless networks," *IEEE Wireless Communications* 9 (4) (2002) 8–27.
- [14] H.S. Kim, T.F. Abdelzaher, W.H. Kwon, "Minimum energy asynchronous dissemination to mobile sinks in wireless sensor networks," in: *Proc. of the First ACM Int. Conf. on Embedded Networked Sensor Systems (ACM Sensys'03)*, November 2003, pp. 193–204.
- [15] T. He, J. Stankovic, C. Lu, T. Abdelzaher, "SPEED: A realtime routing protocol for sensor networks," in: *Proc. IEEE Int. Conf. on Distributed Computing Systems (ICDCS)*, Rhode Island, USA, May 2003, pp. 46–55.
- [16] V. Mhatre, C. Rosenberg, D. Kofman, R. Mazumdar, N. Shroff, "A minimum cost surveillance sensor network with a lifetime constraint," *IEEE Transactions on Mobile Computing*, in press.
- [17] M. Conti, S. Giordano, G. Maselli, G. Turi, "Cross-layering in mobile ad-hoc network design," *IEEE Computer, Special Issue on AdHoc Networks* 37 (2) (2004) 48–51.
- [18] B. Tavli, W. Heinzelman, "TRACE: Time reservation using adaptive control for energy efficiency," *IEEE Journal on Selected Areas of Communication* 21 (10) (2003) 1506–1515.
- [19] M. Caccamo, L.Y. Zhang, L. Sha, G. Buttazzo, "An implicit prioritized access protocol for wireless sensor networks," in: *Proc. IEEE Real-Time Systems Symp.*, December 2002, pp. 39–48.
- [20] J.A. Stankovic, T.F. Abdelzaher, C. Lu, L. Sha, J. Hou, "Real-time communication and coordination in embedded sensor networks," *Proceedings of the IEEE* 91(7) (2003) 1002–1022.
- [21] J. Hill, R. Szewczyk, A. Woo, D. Culler, S. Hollar, K. Pister, "System Architecture Directions for Networked Sensors," *ACM ASPLOS*, 2000, pp. 93-104.
- [22] Jason Liu, L. Felipe Perrone, David M. Nicol, Michael Liljenstam, Chip Elliott, David Pearson, (2001) "Simulation Modeling of Large-Scale Ad-hoc Sensor Networks," European Interoperability Workshop 2001, London England, June 2001.
- [23] Sung Park, Andreas Savvides, and Mani B. Srivastava, (2001) "SIMULATING NETWORKS OF WIRELESS SENSORS", The 2001 Winter Simulation Conference (WSC01), Crystal Gateway Marriott, Arlington, VA, USA, 9-12 December 2001, pp.1330-1338.
- [24] Bren C Mochocki and Gregory R Madey, (2003) "H-MAS: A Heterogeneous, Mobile, Ad-hoc Sensor-Network Simulation Environment," The Seventh Annual Swarm Users/Researchers Conference, Notre Dame, Indiana, April 2003.
- [25] Naval Research Laboratory. NRL's Sensor Network Extension to NS-2. Available at <http://nrlsensorsim.pf.itd.nrl.navy.mil>
- [26] Josh Broch, David A. Maltz, David B. Johnson, Yih-Chun Hu, and Jorjeta Jetcheva, "A Performance Comparison of Multi-Hop Wireless Ad Hoc Network Routing Protocols," *Proceedings of the Fourth Annual International ACM Conference on Mobile Computing and Networking (MobiCom'98)*, Dallas, TX, October 1998.
- [27] The Network Simulator: NS-2. Available at <http://www.isi.edu/nsnam/ns/>
- [28] Charles E. Perkins and Pravin Bhagwat, "Highly Dynamic Destination-Sequenced Distance-Vector Routing (DSDV) for Mobile Computers," In *Proceedings of the SIGCOMM '94 Conference on Communications Architectures, Protocols and Applications*, pp. 234–244, August 1994. A revised version of the paper is available from <http://www.cs.umd.edu/projects/mcml/pub.html>.
- [29] Charles E. Perkins and Elizabeth M. Royer. *Ad Hoc On Demand Distance Vector (AODV) Routing*. Internet-Draft, draft-ietf-manet-aodv-02.txt, November 1998.
- [30] Charles E. Perkins and Elizabeth M. Royer, "Ad-hoc On-Demand Distance Vector Routing," In *Proceedings of the Second IEEE Workshop on Mobile Computing Systems and Applications (WMCSA'99)*, pp. 90–100, New Orleans, LA, February 1999.
- [31] David B. Johnson. Routing in Ad Hoc Networks of Mobile Hosts. In *Proceedings of the IEEE Workshop on Mobile Computing Systems and Applications*, pages 158–163, December 1994.
- [32] David B. Johnson and David A. Maltz. *Dynamic Source Routing in Ad Hoc Wireless Networks*. In *Mobile Computing*, edited by Tomasz Imielinski and Hank Korth, Chapter 5, pp. 153–181. Kluwer Academic Publishers, 1996.
- [33] Josh Broch, David B. Johnson, and David A. Maltz. *The Dynamic Source Routing Protocol for Mobile Ad Hoc Networks*. Internet-Draft, draft-ietf-manet-dsr-03.txt, October 1999.
- [34] David A. Maltz. *On-Demand Routing in Multi-hop Wireless Mobile Ad Hoc Networks*. Ph.D. thesis, CMU-CS-01-130, May 2001, School of Computer Science, Carnegie Mellon University Pittsburgh.
- [35] Dung Van Dinh, "An approach for designing handoff management protocols," in: *Proc. of the 15th IEEE Int. Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC)*, Barcelona, Spain, 5–8 September 2004.