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ROUTING EFFICIENCY IN WIRELESS SENSOR-ACTOR NETWORKS CONSIDERING SEMI-AUTOMATED ARCHITECTURE

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Wireless networks have become increasingly popular and advances in wireless communications and electronics have enabled the development of different kind of networks such as Mobile Ad-hoc Networks (MANETs), Wireless Sensor Networks (WSNs) and Wireless Sensor-Actor Networks (WSANs). These networks have different kind of characteristics, therefore new protocols that fit their features should be developed. We have developed a simulation system to test MANETs, WSNs and WSANs. In this paper, we consider the performance behavior of two protocols: AODV and DSR using TwoRayGround model and Shadowing model for lattice and random topologies. We study the routing efficiency and compare the performance of two protocols for different scenarios. By computer simulations, we found that for large number of nodes when we used TwoRayGround model and random topology, the DSR protocol has a better performance. However, when the transmission rate is higher, the routing efficiency parameter is unstable.

Keywords: Sensor networks, sensor-actor networks, AODV, DSR, MANET.

1 Introduction

Wireless networks have become increasingly popular and they can provide mobile users with ubiquitous communication capability and information access regardless of locations. Conventional wireless networks are often connected to a wired network so that the Internet connections can be extended to mobile users. This kind of wireless network requires a fixed wireline backbone infrastructure. Another type based on radio to radio multi-hopping has neither fixed base stations nor a wired backbone infrastructure. This kind of network is called Mobile Ad hoc NETwork (MANET). A MANET can be seen as an autonomous system or a multi-hop wireless extension to the Internet. As an autonomous system, it has its own routing protocols and network management mechanisms.

Recent advances in wireless communications and electronics have enabled the development of low-cost, low-power, multi-functional sensor nodes that are small in size and communicate in short distances. A sensor network is composed of a large number of sensor nodes that are densely deployed either inside the phenomenon or very close to it. The position of sensor nodes need not be engineered or predetermined. This allows random deployment in inaccessible terrains or disaster relief operations. On the other hand, this also means that sensor network protocols and algorithms must possess self-organizing capabilities.

Although many protocols and algorithms have been proposed for ad hoc networks [1, 2, 3, 4, 5, 6], they are not well suited for the unique features and application requirements of sensor networks. The differences between sensor networks and ad hoc networks are: the number of sensor nodes in a sensor network can be several orders of magnitude higher than the nodes in an ad hoc network; sensor nodes are densely deployed; sensor nodes are prone to failures; the topology of a sensor network changes very frequently; sensor nodes mainly use broadcast communication paradigm whereas most ad hoc networks are based on point-to-point communications; sensor nodes are limited in power, computational capacities, and memory.

Since large number of sensor nodes are densely deployed, neighbour nodes may be very close to each other. Hence, multi-hop communication in sensor networks is expected to consume less power than the traditional single hop communication. One of the most important constraints on sensor nodes is the low power consumption requirement. Therefore, while traditional networks aim to achieve high Quality of Service (QoS) provisions, sensor network protocols must focus primarily on power conservation.

Recently, another class of wireless networks called distributed Wireless Sensor and Actor Networks (WSANs) is emerging. WSAN are capable of observing the physical world, processing the data, making decisions based on the observations and performing appropriate actions. In WSANs, the phenomena of sensing and acting are performed by sensor and actor nodes, respectively. However, in some applications instead of actor nodes, integrated sensor/actor nodes which include both sensing and acting units can also be used. One of the examples of this kind of application is the distributed robot system. In such system, robots which have both sensing and acting capabilities function as integrated sensor actor nodes [7].

Different from Wireless Sensor Networks (WSNs) where the communication takes place between sensors and the sink, in WSANs, new networking phenomenons called sensor-actor and actor-actor communications may occur. Sensor-actor communication provides the transmission of event features from sensors to actors. After receiving event information, actors need to communicate with each other in order to perform the appropriate action on the event area.

An important aspect which should be considered for MANETs, WSNs and WSANs is the communication reliability and congestion control. In traditional wired nets, one reasonably supposes that communication paths are stable along the transmission instances. This fact permits to use the end-to-end approach to the design of reliable transport and application protocols. The TCP works well because of the stability of links. On the other hand, in MANETs, WSNs and WSANs paths can change over time, because of time-varying characteristics of links and nodes reliability. These problems are important especially in a multi-hop scenario, where nodes accomplish also at the routing of other nodes' packets.

In this paper, we study the behaviour of two routing protocols: Dynamic Source Routing (DSR) and Ad-hoc On-demand Distance Vector (AODV) using TwoRayGround and Shadowing radio models, and lattice and random topologies. We compare the performance of two protocols based on the concept of Routing Efficiency (RE). As a technique for congestion control in our model, we use the packet repetition transmission. The repetition rate depends on a number of other factors, first of all the bound on the signal distortion perceived at the sink node. In our simulation system, we consider a semi-automated architecture of the WSAN. In this case, there is no need to develop sophisticated distributed algorithms to perform communication and coordination, and the architecture is similar with WSN applications. So, we concentrate more in the density of the number of nodes in the network. We are extending now the simulation system for the case of automated architecture.

The paper is organized as follows. In Section 2, we introduce the related work. In Section 3, we will present WSAN architecture and the proposed simulation system. In Section 4, we present routing protocols. In Section 5, we discuss the RE concept. In Section 6, we show the simulation results. Finally, the conclusions are given in Section 7.

2 Related Work

During last few years, there are many research work on the performance evaluation of WSNs and ad-hoc networks [8, 9, 10, 11, 12, 13, 14]. However, all these works are concentrated with techniques, protocols and algorithms for ad hoc networks or WSNs.

To the best of our knowledge, there are only few studies that deal with WSANs. In [7], the authors deal with coordination and communication problems in WSANs. General differences between WSNs and WSANs are explored, and the physical architecture of WSANs is outlined. Furthermore, the authors discusses sensor/actor and actor/actor coordination problems and they explore the requirements in communication protocols occurring due to the presence of actors. However, there is not shown and simulation or evaluation results.

In [15], the focus of the authors is to investigate the operation and control in WSANs. The main issues addressed by self-organization techniques are scalability, network lifetime, and real-time support. The authors developed a system named Rule-based Sensor Network (RSN) according to the observed communication and control behavior in cellular communication. Information between cells are transmitted via proteins and result in the cascade of protein/protein or protein/DNA interactions to produce a specific cellular answer. The processes are programmed in every individual cell and lead to a coordinated reaction on a higher organization platform. They transferred these mechanisms to operation and control in

WSANs. They presented some simulation results to show the feasibility of their approach.

In [16], the authors present a coordination framework for WSANs. They proposed a sensor-actor coordination model based on an event-driven clustering paradigm in which cluster formation is triggered by an event so that clusters are created on-the-fly to optimally react to the event itself and provide the required reliability with minimum energy expenditure. The optimal solution is determined by mathematical programming and a distributed solution is also proposed. They also introduced a model for actor-actor coordination for a class of coordination problems in which the area to be acted upon is optimally split among different actors. An auction-based distributed solution of the problem is also presented. By performance evaluation they show that a real-time constraints and minimum energy consumption can be reached in the proposed framework with simple interactions between sensors and actors that are suitable for large-scale networks of energy-constrained devices.

Different from these works, in our simulation system, we consider the trade-off of different protocols, radio models and topologies of WSANs.

3 WSAN Architecture and Proposed Network Simulation Model

In WSANs, the roles of sensor and actor nodes are to collect data from the environment and perform appropriate actions based on the collected data. As shown in Fig. 1, the nodes are scattered in the sensor/actor field while the sink which monitors the overall network is separated from the sensor/actor field.

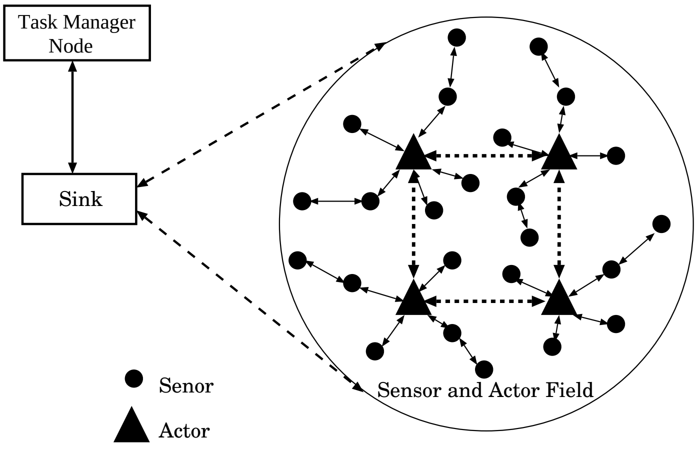

Fig. 1. WSAN architecture.

After sensors in the sensor/actor field detect a phenomenon, they can transmit their readings to actor nodes which can process all incoming data and initiate appropriate actions, or route data back to the sink which issues action commands to actors. For this reason, WSAN have two kind of architectures: automated architecture and semi-automated architecture. These two architectures are given in Fig. 2. and Fig. 3. Depending on the types of applications, one of these architectures may be used.

The advantage of the semi-automated architecture is that there is no need to develop sophisticated distributed algorithms to perform communication and coordination. Moreover,

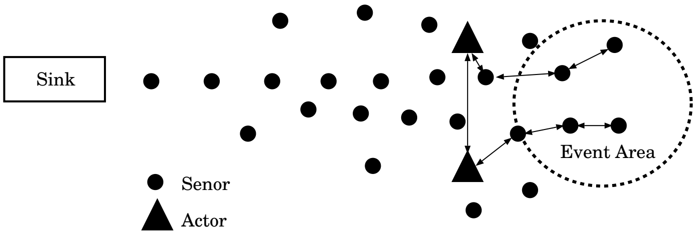

Fig. 2. WSAN automated architecture.

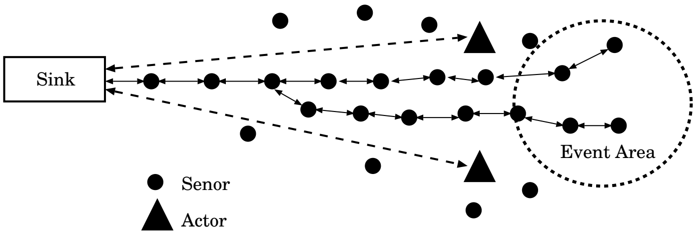

Fig. 3. WSAN semi-automated architecture.

this is similar to the architecture already used in WSN applications. While, in automated architecture, the information sensed is conveyed quickly from sensors to actors, since they are close to each other and the latency can be minimized. Also, the automated architecture has low energy consumption and long network lifetime compared with semi-automated architecture, but the communication and coordination mechanisms are needed.

In general, WSAN can be seen as a combination of WSN and MANETs. Sensor nodes are typically less mobile, more limited in capabilities, and more densely deployed than nodes in MANETs. In this paper, we propose and implement a network simulation model as shown in Fig. 4. We consider the semi-automated architecture, thus we are concentrated more on the density of the number of nodes. The sensor node model is shown in Fig. 5. The channel 1 is used for neighbor nodes communication and channel 2 for communication between present node and event node.

In our simulation model, every node detects the physical phenomenon and the actor node is more powerful than sensor nodes. This model can be used for remote monitoring of hazard or inaccessible areas [17]. We analyze the performance of the network in a fixed time interval, τ. This can be considered as the available time for the detection of the phenomenon and its value is application dependent.

So far two types of topologies has been studied: the random and lattice deployments. In the former, nodes are supposed to be uniformly distributed inside, while in the latter nodes are vertexes of particular geometric shape, e.g. a square grid. In this case, in order to guarantee the connectedness of the network we should set the transmission range of every node to the step size, d, which is the minimum distance between two rows (or columns) of the grid. In fact, by this way the number of links that every node can establish is 4 (the node degree is $D = 4$). By using Cooper's theorem [18] along with some power control techniques, one could

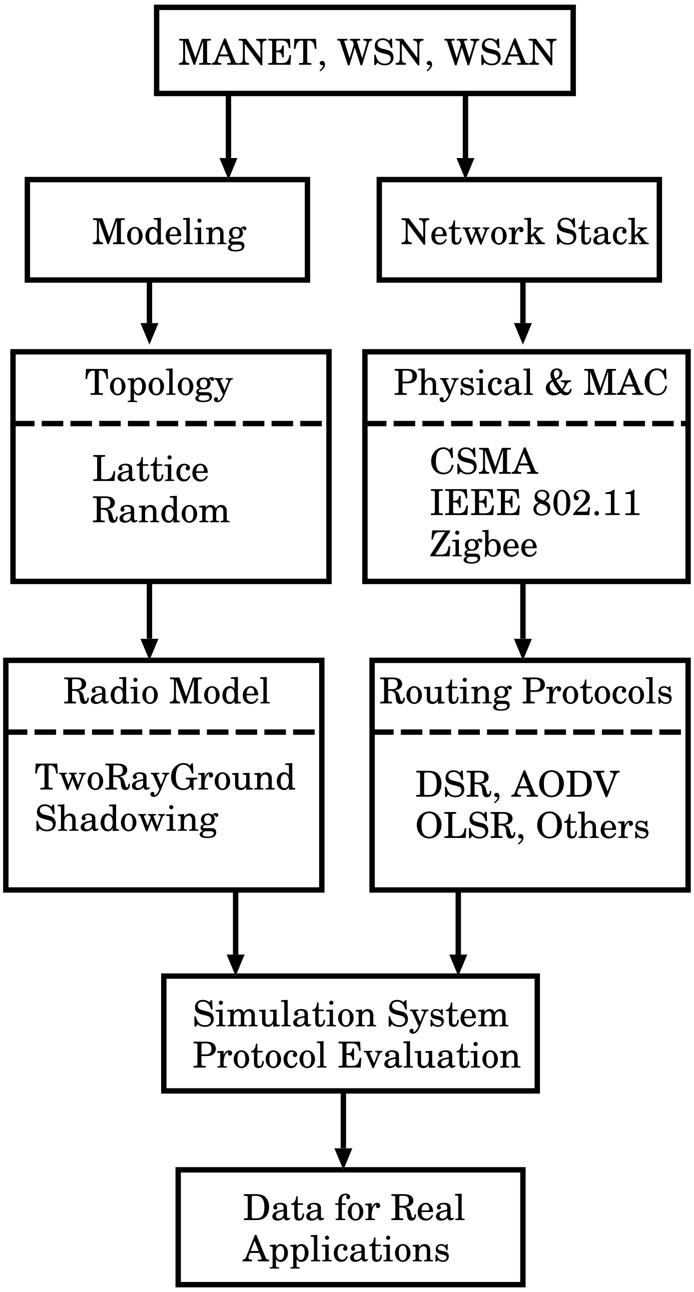

Fig. 4. Proposed network simulation model.

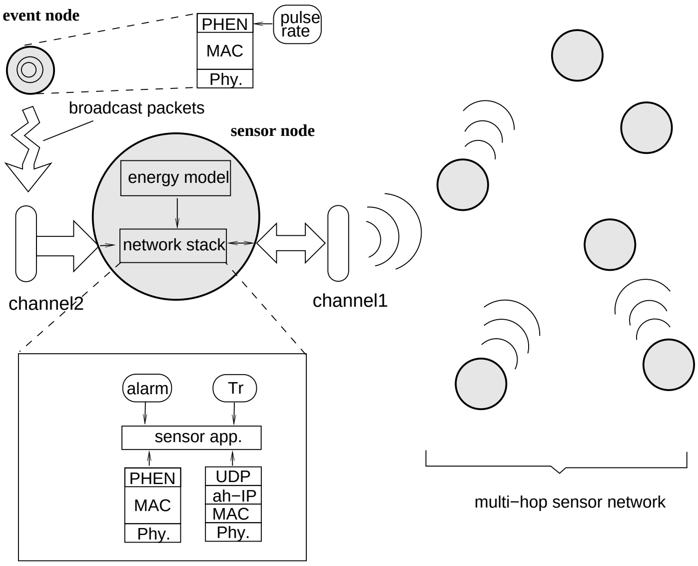

Fig. 5. Sensor node model.

use also $D = 2$.[a] However, we assume all nodes to be equal and then the degree is fixed to 4. Nodes at the borders have $D = 2$.

3.1 Sensor Node and Phenomenon Model

In order to simulate the detection of a natural event, we used the libraries from Naval Research Laboratory (NRL) [20]. In this framework, a phenomenon is modeled as a wireless mobile node. The phenomenon node broadcasts packets with a tunable synchrony or pulse rate, which represents the period of occurrence of a generic event.[b] These libraries provide the sensor node with an alarm variable. The alarm variable is a timer variable. It turns off the sensor if no event is sensed within an alarm interval. In addition to the sensing capabilities, every sensor can establish a multi-hop communication towards the Monitoring Node (MN) by means of a particular routing protocol. This case is the opposite of the polling scheme. We used two kind of reactive protocols: AODV and DSR.

Sensor node is composed of sensor function model and power model. The sensor function model consists of sensor channel and wireless channel. In the wireless channel is included the physical layer, MAC layer and Network layer. To build the sensor function model, we integrated the sensor protocol stack with the wireless protocol stack.

We assume that the MAC protocol is the IEEE 802.11 standard. This serves us as a baseline of comparison for other contention resolution protocols. The receiver of every sensor node is supposed to receive correctly data bits if the received power exceeds the receiver

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[a] By using the theorem in [18], we can say that a simple 2 regular network is almost surely strongly 2 connected [19].

[b] As a consequence, this model is for discrete events. By setting a suitable value for the pulse rate, it is possible in turn to simulate the continuous signal detection such as temperature or pressure.

threshold, γ. This threshold depends on the hardware.[c] As reference, we select parameters values according to the features of a commercial device (MICA2 OEM). In particular, for this device, we found that for a carrier frequency of $f = 916$MHz and a data rate of 34KBaud, we have a threshold (or receiver sensitivity) $\gamma|_{dB} = -118$dBm [21].

3.2 Radio Model and Transmission Power

Two main phenomena affect the received power at a certain distance. The first one is the free space propagation of electromagnetic waves. These in turn can be reflected by surrounding objects and terrain as well, and in general are attenuated with the distance according to a power law relation. The second one accounts for the fact that surrounding clutters may be different at two different locations, and then the received power is in general different even if the transmitter-receiver separation is constant. It is the so called Shadowing or large-scale path loss, in contrast with its counterpart, the small-scale path loss or fading which accounts for impairments due to time-frequency variations of the radio channel. Measurements within real WSN, MANETs and WSANs demonstrate that these variations are of concern. However, the right model of the radio randomness strongly depends on the radio environment as well as the transmitter characteristics.

The Shadowing model assumes that the power of received node is:

$$P_r(d)|_{\text{dB}} = \underbrace{P_t|_{\text{dB}} - \beta_0 - 10\alpha \log\left(\frac{d}{d_0}\right)}_{\text{deterministic part}} + \underbrace{S_{\text{dB}}}_{\text{random part}} \tag{1}$$

where β_0 is a constant. The term S_{dB} is a random variable, which accounts for random variations of the path loss. This variable is also known as log-normal Shadowing, because it is supposed to be Gaussian distributed with zero mean and variance σ^2_{dB}, that is $S_{\text{dB}} \sim \mathcal{N}(0, \sigma^2_{\text{dB}})$. Given two nodes, if $P_r > \gamma$, where γ is the hardware-dependent threshold, the link can be established. The case of $\sigma = 0$, $\alpha = 4$, $d > d_0$ is called the TwoRayGround model and it is a deterministic model [22]. In this work, we will use both Shadowing and TwoRayGround radio models.

3.3 Lattice and Random Networks

3.3.1 Lattice Network

$D = 2$ guarantees a connected network. It should be noted that this condition does not consider the quality of an individual link, generally measured by the Signal-to-Noise Ratio (SNR) and/or the Bit Error Probability (BER). In other words, from a communication point of view, two nodes can be inside their radio range, but the BER can be very low. This means that the BER does not correlate with the distance. The reason of this fact is that in WSNs and WSANs the background noise, the multipath propagation, the imperfections of hardware and the variance of battery power cannot be neglected. Here, we assume that the packet losses are caused by the shared access to the radio medium by several nodes. Thus, it suffices to guarantee a value of $Prob(D \geq 2)$ as close as possible to 1. To this aim, the link between any two nodes is a Bernoullian random variable with a certain probability p. If we consider only

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[c] Other MAC factors affect the reception process, for example the Carrier Sensing Threshold (CST) and Capture Threshold (CP) of IEEE.802.11 used in NS-2.

the closest neighbors, we have that $Prob(D \geq 2) \geq \sum_{2\leq k\leq 4} \binom{N}{k} p^k \left(1-p\right)^{N-k}$. For $p = 0.95$, $Prob(D \geq 2) \approx 0.9995$. Thus, based on the grid step d and Eq. (1), we can set the maximum transmission range by solving $p = Prob\left\{ P_r(d)|_{\text{dB}} > \gamma|_{\text{dB}} \right\} = 0.95$. It is straightforward to show that:

$$P_t(d)|_{\text{dB}} = \left[10\alpha \log_{10} d + \gamma|_{\text{dB}} - \text{erfc}^{-1}(2p)\sqrt{(2)}\sigma \right] + \beta_0 \,, \tag{2}$$

where erfc^{-1} is the inverse of the standard error function. This formula provides the transmission power of each node, given a transmission range and a probability or rate of coverage p. An obvious effect of the Shadowing is the random coverage of the transmission range of each node. We will have different received powers in different directions. Consequently, the real coverage radius is not constant as in the ideal isotropic radiation case.

3.3.2 Random Networks

In the case of random networks, we suppose that the coordinates in the Euclidean plane of every node are random variables uniformly distributed in the interval $[0, L] \times [0, L]$. To take into account the Shadowing effects, we shall modify the formula of the transmission range. In particular, by giving the following definition,

$$\zeta \triangleq \left(\frac{\ln(10)\sigma}{10\alpha} \right)^2 \,, \tag{3}$$

we have that the transmission range is:

$$r_0 \geq \sqrt{\frac{\ln\left(\frac{\ln P(conn)}{-\rho A}\right)}{-\pi\rho e^{2\zeta}}} \,, \tag{4}$$

where $P(conn)$ is the connectivity probability and A is the physical area of the network. The Eq. (4) makes use of the fact that the distribution of nodes in the plane is a 2-dimensional Poisson process with intensity ρA. However, given the equality of variance and mean in the Poisson process, we use this formula also for the uniform distribution of nodes. Accordingly, the transmission power is set as:

$$P_t = \gamma\beta_0 r_0^\alpha \,,$$

where r_0 is computed by Eq. (4). In fact, we compute r_0 for the lowest ρ only. For example, for $\rho = 25 \cdot 10^{-6}$nodes/m^2 and $P(1 - conn) = 0.4$, we have $r_0 = 180$m, as shown in Table 1. Then, we use the same r_0 also for $\rho > 25 \cdot 10^{-6}$. It is worth noting that $P(1 - conn) = 0.4$ is enough to guarantee on average a “practically” connected network, i.e. then number of sensor nodes which are isolated can be neglected.

3.4 Interference

In general, in every wireless network the electromagnetic interference of neighbouring nodes is always present. The interference power decreases the SNR at the intended receiver, which will perceive a lower bit and/or packet error probability. Given a particular node, the interference power depends on how many transmitters are transmitting at the same time of the

Table 1. Topology settings.

Lattice	
Step (m)	$d = \frac{L}{\sqrt{N}-1}$
Service Area Size (m^2)	$L^2 = (800\text{x}800)$
Number of Nodes	$N \in \{16, 64, 256\}$
Transmission Range (m)	$r_0 = d$
Random	
Density (nodes/m^2)	$\rho \in \{25 \cdot 10^{-6}, 2 \cdot 10^{-4}\}$
Transmission Range (m)	$r_0 = 180$

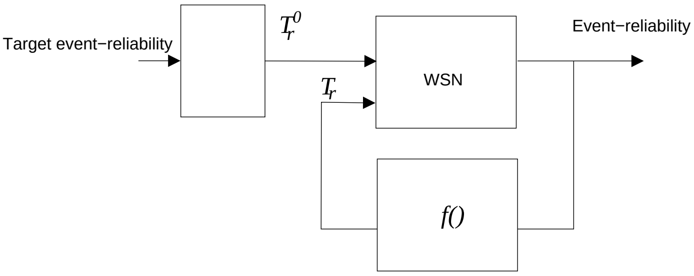

Fig. 6. Representation of the transport based on the event-reliability.

transmission for the given node. In a WSAN, since the number of concurrent transmissions is low because of the low duty-cycle of sensors and actors, we can neglect the interference. In other words, if we define duty-cycle as the fraction between the total time of all transmissions of sensor or actor data and the total operational time of the net, we get always a value less than 0.5. In fact, the load of each sensor is $\ll 1$ because the data are transmitted only when an event is detected [9]. However, it is intuitive that in a more realistic scenario, where many phenomena trigger many events, the traffic load can be higher, and then the interference will worsen the performance with respect to that we study here. Consequently, we can fairly say that the results we get here should be considered as an upper bound on the system performance with respect to more realistic scenarios.

3.5 Event Detection and Transport

Here, we use the data-centric model similar to [10], where the end-to-end reliability is transformed into a bounded signal distortion concept. In this model, after sensing an event, every sensor node sends sensed data towards the sink node and the sink node communicate with the actor node to carried out the action. The transport used is a UDP-like transport, i.e. there is not any guarantee on the delivery of the data. While this approach reduces the complexity of the transport protocol and well fit the energy and computational constraints of nodes, the event-reliability can be guaranteed to some extent because of the spatial redundancy. The node transmits data packets reporting the details of the detected event at a certain transmission rate.[d] The setting of this parameter, T_r, depends on several factors, as the quantization step of sensors, the type of phenomenon, and the desired level of distortion perceived at the

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[d] Note that in the case of discrete event, this scheme is a simple packet repetition scheme.

actor node. In [10], the authors used this T_r as a control parameter of the overall system. For example, if we refer to event-reliability as the minimum number of packets required at sink node in order to reliably detect the event, then whenever the sink node receives a number of packets less than the event-reliability, it can instruct sensor nodes or actor nodes to use a higher T_r. This instruction is piggy-backed in dedicated packets from the sink node. This system can be considered as a control system, as shown in Fig. 6, with the target event-reliability as input variable and the actual event-reliability as output parameter. The target event-reliability is transformed into an initial T_r^0. The control loop has the output event-reliability as input, and on the basis of a particular non-linear function $f(\cdot)$, T_r is accordingly changed. We do not implement the entire control system, but only a simplified version of it. For instance, we vary T_r and observe the behavior of the system in terms of the mean number of received packets. In other words, we open the control loop and analyze the forward chain only.

4 Routing Protocols

4.1 Proactive and Reactive Routing Protocols

Reactive routing protocols, such as DSR and AODV routing protocols, are source-initiated on-demand routing protocols. These types of routing protocols create routes only when requested by the source node. When a node requires a route to a destination, it initiates a route discovery process within the network. This process is completed once a route is found or all possible route permutations have been examined. Once a route is established, it is maintained by a route maintenance procedure either until the destination becomes inaccessible along every path from the source or until the route is no longer needed. This approach can adjust quickly to route changes and does not introduce overhead for periodic control messages when routes are cached or when the network is idle. However, discovering a new route from scratch on demand is costly and bad routes are detected at the cost of packet drops.

Proactive routing protocols, such as the Destination-Sequenced Distance-Vector (DSDV), the Topology Broadcast Based on Reverse-Path Forwarding (TBRPF) routing protocols, Optimized Link State Routing (OLSR), maintain up-to-date routing information using periodic control messages. Therefore, proactive routing protocols are ready to exchange packets at anytime. Each node using a proactive routing algorithm maintains one or more tables to store routing information and responds to changes in network topology by propagating updates throughout the network to maintain a consistent view of the network. The areas in which different protocols vary are the number of necessary routing-related tables and the methods by which nodes disseminate changes in network structure.

4.2 AODV and DSR Routing Protocols

We are aware of many proposals of routing protocols for ad-hoc networks. Here, we consider reactive protocols such as AODV and DSR. The AODV and DSR build up a route only when it is needed, i.e. when a node has data to send [14]. In AODV and DSR, there are two phases: Route Request (RREQ) and Route maintenance. The RREQ phase is accomplished by means of broadcast messages to neighbor nodes. In AODV, the destination node chooses one among all possible discovered routes. While in DSR, the source node can learn multiple routes towards the destination. AODV maintains per destination routing tables, while DSR

Table 2. Radio model and system parameters.

Radio Model Parameters	
Path Loss Coefficient	$\alpha = 2.7$
Variance	$\sigma^2_{\mathrm{dB}} = 16$ dB
Carrier Frequency	916 MHz
Antenna	omni
Threshold (Sensitivity)	$\gamma = -118$ dB
Other Parameters	
Reporting Frequency	$T_r = [0.1, 1000]$ packet per seconds(pps)
Interface Queue Size	50 packets
UDP Packet Size	100 bytes
Detection Interval τ	30 s

contains multiple routes cache entries for each destination. Moreover, in DSR there is not any mechanism to check whether a cached routed has become staled. For AODV protocol, it is expected that the impact of radio link dynamics is minimal, because of the multi-round mechanism. However, the performance also depends on the infrastructure.

5 Routing Efficiency

In this section, we introduce the concept of RE. We consider that after a sensor node detects the physical phenomenon, it sends the packets to the sink node via a routing protocol. Then the sink node communicate with actor node to carry out an appropriate action. The ability to transmit packets for different protocols is different. Also, the RE of a protocol is affected by many network parameters such as wireless transmission radio model, network topology, and transmission frequency. In order to compare the performance of different protocols, we consider the same simulation environment. For our system, we used TwoRayGround and Shadowing radio models and lattice and random topologies.

We defined the RE parameter as the ratio of sent packets from sensing node with sent packet by routing protocol. Thus:

$$RE(\tau) = \frac{N_{sent}(\tau)}{N_{routing}(\tau)} \tag{5}$$

where $N_{routing}(\tau)$ is the number of sent packets by routing protocol, and $N_{sent}(\tau)$ is the number of sent packets by sensor or actor nodes. These quantities are computed in a time interval of τ seconds. For the same simulation time, when RE value is high, the protocol routing efficiency is better. Considering Eq.(5), when $N_{sent}(\tau)$ value is increased and the $N_{routing}(\tau)$ value is decreased, the RE is increased. The number of sent packets by sensor node or actor nodes is higher than the number of packet sent by routing protocol. For this reason, the RE function is an increasing function as shown in Fig. 7. The RE is proportional to the transmission rate.

6 Simulation Results

In this section, we present the simulation results. We simulated the network by means of NS-2 simulator with the support of NRL libraries. Since the number of scheduler events can be

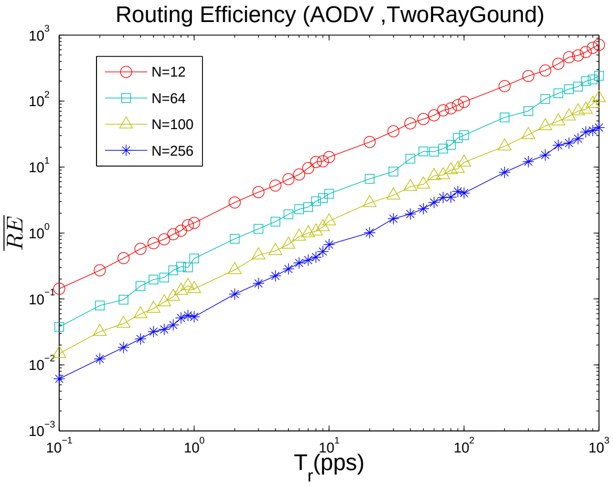

Fig. 7. Sample averages of RE for AODV, TwoRayGround model and lattice topology.

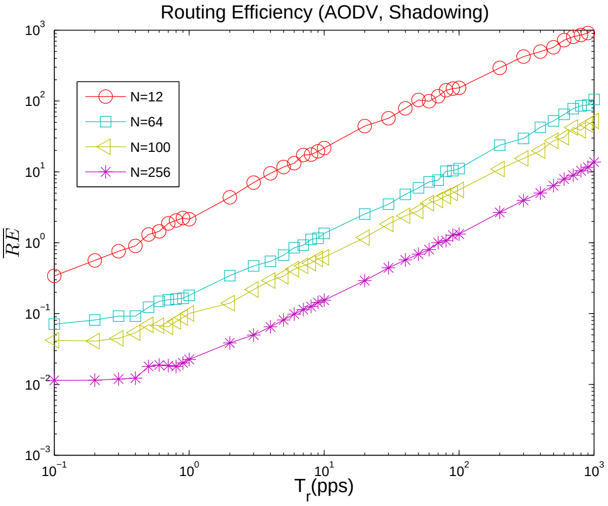

Fig. 8. Sample averages of RE for AODV and Shadowing model in lattice topology.

very high, we applied a patch against the scheduler module of NS-2 in order to speed up the simulation time. The radio model parameters are listed in Table 2. For each routing protocol, the sample results of Eq.(5) are computed over 20 simulation runs, and they are plotted in Fig. 7 to Fig. 12.

In Fig. 7 are shown the results of lattice topology, when we used AODV protocol and TwoRayGround radio model. When the number of nodes is increased, the number of routes is increased, thus the searching time to find a route for AODV also is increased. When the number of nodes is 256, the RE of AODV is the worst in our simulation. In Fig. 8, we show

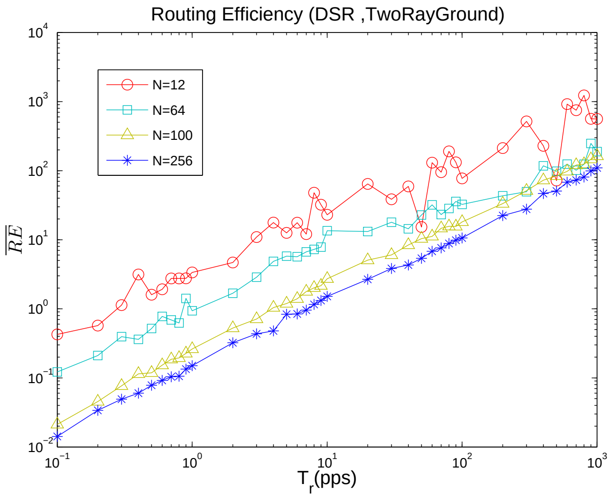

Fig. 9. Sample averages of RE for DSR, TwoRayGround model and lattice topology.

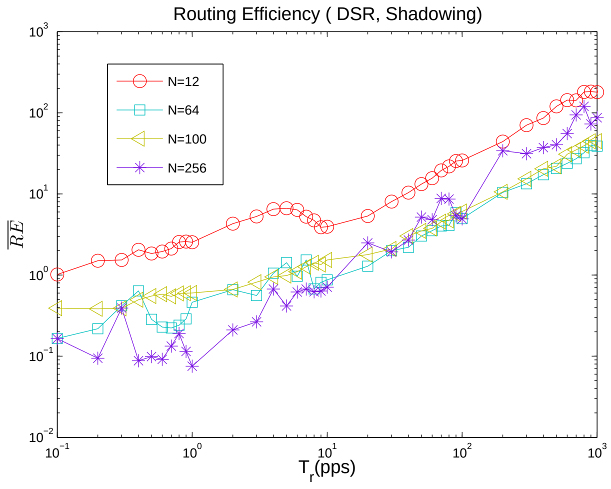

Fig. 10. Sample averages of RE for DSR, Shadowing model and lattice topology.

the results for the case of Shadowing radio model. The RE in the case of 12 and 256 nodes compared with TwoRayGround model is higher. While for 64 and 100 nodes is a little bit lower. This is because the transmission range of Shadowing is not regular like TwoRayGround model.

In the case of the DSR when we used lattice topology and TwoRayGround model as shown in Fig. 9, with increase of the number of nodes the RE is also decreased. However, comparing with AODV in Fig. 7 for the same time interval and for the same number of nodes, the RE of DSR is better. For instance, looking to the simulation results, when the number of nodes

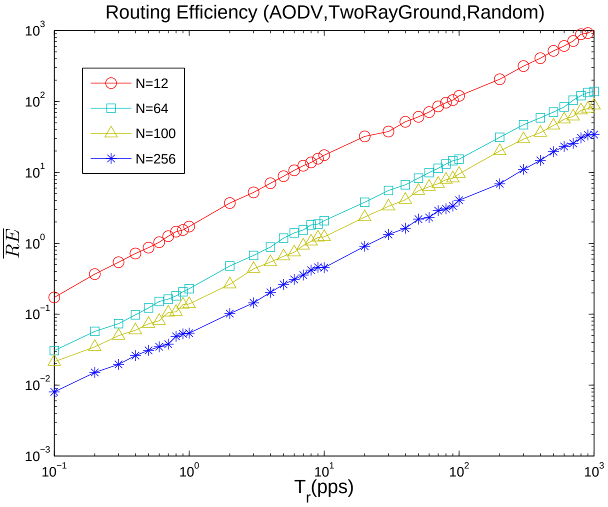

Fig. 11. Sample averages of RE for AODV, TwoRayGround model and random topology.

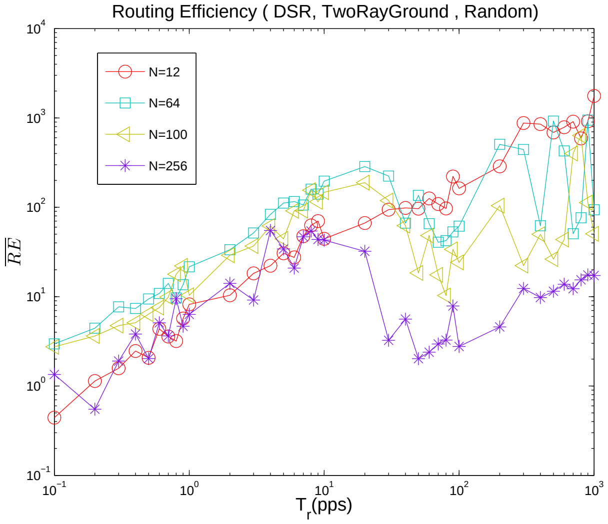

Fig. 12. Sample averages of RE for DSR, TwoRayGround model and random topology.

is 12 and T_r=10, the RE of AODV is 8, while for DSR is 11. When there are 256 nodes, the RE of AODV is 0.1, but for DSR is 0.5. For T_r=100, when the number of nodes is 12, the RE of AODV is 50, while for DSR is 100. When the number of nodes is 12 and 256, the RE of DSR is better than AODV. However, for 12 nodes, the RE of DSR shows fluctuations.

In Fig. 10, we show the simulation results for DSR when we consider the lattice topology and Shadowing radio model. If we compare these results with AODV for the same radio model (Fig. 8), in the case of 256 nodes, the RE of DSR is better than AODV. However, when number of nodes is small the RE of AODV is better than DSR.

In Fig. 11 and Fig. 12, we show the simulation results for random topology and TwoRayGround model considering AODV and DSR protocols. If we compare Fig. 7 with Fig. 11 (in this case we compare lattice and random topologies), the RE of random topology is better that lattice topology. If we compare Fig. 11 and Fig. 12 (in this case we compare AODV and DSR for TwoRayGround model), DSR has better performance than AODV.

7 Conclusions

In this work, we presented a simulation system for WSANs. We considered the case of semi-automated architecture. Our goal is to find the trade-off relations between different scenarios based on the density of the number of nodes, topologies, radio models and protocols.

In this paper, we considered the performance behaviour of two protocols: AODV and DSR using TwoRayGround and Shadowing models for lattice and random topologies. We study the RE and compare the performance of two protocols for different scenarios. By computer simulations, we found that for large number of nodes when we used TwoRayGround model and random topology, the DSR protocol has a better performance. However, when the transmission rate is higher, the RE parameter is unstable.

Using the data from our simulation system, we would like to build a testbed to test real protocols. Also, we are working to implement new protocols for WSANs.

In the future, we would like to carry out more extensive simulations to evaluate the RE also for other protocols. We are extending now the simulation system for automated architecture of WSANs.

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References

1. A. Durresi, V. Paruchuri, M. Durresi, Leonard Barolli (2006), *Qos-Energy Aware Broadcast for Heterogeneous Wireless Ad Hoc Networks*, Journal of Mobile Multimedia, Vol. 2, No. 2, pp. 344-358.
2. T. R. Sheltami (2008), *Performance Evaluation of H.264 Protocol in Ad Hoc Networks*, Journal of Mobile Multimedia, Vol.4 No.1 pp. 59-70.
3. V. Pham, E. Larsen, O. Kure and P. Engelstad (2009), *Routing of Internal MANET Traffic over External Networks*, Mobile Information Systems, Vol. 5, No. 3, pp. 291-311.
4. M. Ikeda, L. Barolli, G. De Marco, T. Yang, A. Durresi, F. Xhafa (2009), *Tools for Performance Assessment of OLSR Protocol*, Mobile Information Systems, Vol. 5, No. 2, pp. 165-176.
5. S. Mahfoudh, P. Minet (2009), *Maximization of Energy Efficiency in Wireless Ad Hoc and Sensor Networks with SERENA*, Mobile Information Systems, Vol. 5, No. 1, pp. 33-52.
6. A. M. Hanashi, I. Awan, M. Woodward (2009) *Performance Evaluation with Different Mobility Models for Dynamic Probabilistic Flooding in MANETs*, Mobile Information Systems, Vol. 5, No. 1, pp. 65-80.
7. I. F. Akyildiz and I. H. Kasimoglu (2004), *Wireless Sensor and Actor Networks: Research Challenges*, Ad Hoc Networks Journal (Elsevier), Vol. 2, No. 4, pp. 351-367.
8. O. Younis and S. Fahmy (2004), *HEED: A Hybrid, Energy-efficient, Distributed Clustering Approach for Ad-hoc Sensor Networks*, IEEE Transactions on Mobile Computing, Vol. 3, No. 4, pp.

366-379.

9. W. Ye, J. Heidemann, and D. Estrin (2004), *Medium Access Control with Coordinated Adaptive Sleeping for Wireless Sensor Networks*, IEEE/ACM Transaction Networking, Vol. 12, No. 3, pp. 493-506.
10. Ö. B. Akan and I. F. Akyildiz (2005), *Event-to-sink Reliable Transport in Wireless Sensor Networks*, IEEE/ACM Transactions on Networking, Vol. 13, No. 5, pp. 1003-1016.
11. M. C. Vuran, V. C. Gungor, O. B. Akan (2005), *On the Interdependency of Congestion and Contention in Wireless Sensor Networks*, Proc. of CST SenMetrics-2005, http://www.cse.unl.edu/∼mcvuran/Interdep-SenMetrics.pdf.
12. S. Giordano, C. Rosenberg (2006), *Topics in Ad Hoc and Sensor Networks*, IEEE Communication Magazine, Vol. 44, No. 4, pp. 97-97.
13. J. N. Al-Karaki, A. E. Kamal (2004), *Routing Techniques in Wireless Sensor Networks: A Survey*, IEEE Wireless Communication, Vol. 11, No. 6, pp. 6-28.
14. C. Perkins (Editor) (2001), *Ad Hoc Networks*, Addison-Wesley.
15. F. Dresslera, I. Dietricha, R. Germana, B. Krugerb (2009), *A Rule-based System for Programming Self-organized Sensor and Actor Networks*, Computer Networks, Vol. 53, No. 10, pp. 1737-1750.
16. T. Melodia, D. Pompili, V. C. Gungor, I. F. Akyildiz (2005), *A Distributed Coordination Framework for Wireless Sensor and Actor Networks*, Pror. of 6th ACM International Symposium on Mobile Ad Hoc Networking and Computing, Urbana-Champaign, IL, USA, pp. 99-110.
17. G. W. Allen, K. Lorincz, O. Marcillo, J. Johnson, M. Ruiz and J. Lees (2006), *Deploying a Wireless Sensor Network on an Active Volcano*, IEEE Internet Computing, Vol. 10, No. 2, pp. 18-25.
18. C. Cooper (1993), *A Note on the Connectivity of 2-regular Digraphs*, Random Structures Algorithms, Vol. 4, pp. 469-472.
19. T. Yang, G. De Marco, M. Ikeda, and L. Barolli (2006), *A Case Study of Event Detection in Lattice Wireless Sensor Network with Shadowing-induced Radio Irregularities*, Proc. of the 4-th International Conference on Advances in Mobile Computing and Multimedia (MoMM-2006), pp. 241-250.
20. I. Donward (2004), *NRL's Sensor Network Extension to NS-2*, Available on line at http://pf.itd.nrl.navy.mil/nrlsensorsim/.
21. Crossbow Technology, Inc., Available on Line at http://www.xbow.com/.
22. T.S. Rappaport (Editor) (2001), *Wireless Communications*, Prentice Hall PTR.