A Simulation System for WSNs as a Digital Eco-System Approach Considering Goodput Metric

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***Abstract*—Sensor networks are a sensing, computing and communication infrastructure that are able to observe and respond to phenomena in the natural environment and in our physical and cyber infrastructure. The sensors themselves can range from small passive micro-sensors to larger scale, controllable weather-sensing platforms. In order to simulate Wireless Sensor Networks (WSNs), we implemented a simulation system as a Digital Eco-System (DES) approach. We implement our system as a multi-modal system considering different topologies, radio models, routing protocols, MAC protocols, and different number of nodes. However, in this work, we consider the goodput metric and evaluate the performance of WSN for AODV and TwoRayGround model considering different topologies and number of nodes. To reduce the consumed energy of a large scale WSN network, we consider a mobile sink node in the observing area. We investigate how the sensor network performs in the case when the sink node moves. We compare the simulation results for two cases: when the sink node is mobile and stationary. The simulation results have shown that for the case of mobile sink, the goodput of random topology is better than the case of lattice. In the case of stationary sink, the goodput is unstable. In case of mobile sink, the goodput is stable and better than in case of stationary sink.**

***Keywords*-WSN; Digital Eco-System; Radio Model; Goodput; WSN Topology.**

I. Introduction

In the Wireless Sensor Networks (WSNs), a large number of nodes, having both computing power and wireless communication capability, are embedded in the environment, collect sensor data, and report to the sink. WSN, have wide range of applications and can be categorized into monitoring space and monitoring things. WSNs can be considered as a special type of Ad Hoc wireless sensor networks, where sensor nodes are, in general, stationary. A unique feature of sensor networks is the cooperative effort of sensor nodes. Sensor nodes are usually fitted with on-board processors. Instead of sending the raw data to the nodes responsible for the fusion, they use their processing abilities to locally carry out simple computations and transmit only the required and partially processed data. A sensor system normally consists of a set of sensor nodes operating on limited energy and a base system without any energy constraint called sink. Typically, the sink serves as the gathering point for the collected data. The sink also broadcasts various control commands to sensor nodes.

There are many applications of sensor networks. For instance, in military application, the rapid deployment, self-organization, and fault-tolerance characteristics of sensor nodes make them a promising, surveillance, reconnaissance, and targeting systems. In health car, sensor nodes can be used to monitor patients and assist disabled patients. Other applications include managing inventory, monitoring product quality, and monitoring disaster areas.

Recently, there are many research work for sensor networks [1], [2], [3], [4]. In our previous work [5], we implemented a simulation system for sensor networks considering different protocols and different propagation radio models. In this paper, we study a particular application of WSN for event-detection and tracking. The application is based on the assumption that WSN present some degree of spatial redundancy. For instance, whenever an event happens, a certain event data is transmitted to the sink node. Because of the spatial redundancy, we can tolerate some packet loss, as long as the required detection or event-reliability holds. This reliability can be formulated as the minimum number of packets required by the sink node in order to re-construct the event field. We want to investigate the performance of

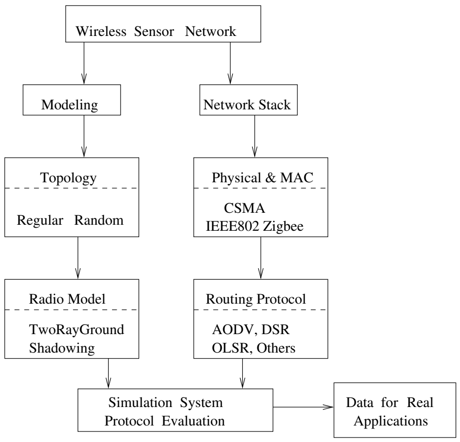

Figure 1. Network simulation model.

WSN for different topologies considering a single mobile sink. In the large scale network, the sink node is faraway from the sensor nodes. For this reason, it is needed more energy to send the sensed data. To reduce the consumed energy of sensor node we consider the mobile sink for the large scale networks.

We are currently witnessing an increasing need to design and deploy multi-featured networking applications instead of stand alone applications for specific needs. Such applications combine different paradigms and are developed using various technologies with the aim of achieving a multi-disciplinary view. The Digital Eco-Systems (DES) [6], [7], [8] are emerging as a paradigm for supporting multi-disciplinary and multi-paradigmatic applications capable of being adaptive and socio-technical, having properties of self-organization inspired by natural ecosystems. Important features of such applications include the capability to be self-organized, decentralized, scalable and sustainable as well as integration of different types of resources (ad-hoc terminals and sensor devices) providing global, transparent and secure access to resources. Supporting various forms of collaboration and trade-offs is also important in such systems. In fact, DES are considered as the next generation of collaborative environments.

In this work, we implement an simulation system for WSN as a DES approach considering goodput as a metric for evaluation. Different from other works, we implement a multi-modal system considering the trade-offs between propagation radio models, network protocols, MAC protocols, different topologies and different number of nodes.

The remainder of the paper is organized as follows. In Section II, we explain the proposed network simulation model. In Section III, we discuss the goodput metric. In Section IV, we show the simulation results. Conclusions of the paper are given in Section V.

II. Proposed Network Simulation Model

The development of DES requires the combination of many computing paradigms and technologies. For this reason, we consider the combination of different propagation radio models, network protocols, MAC protocols, different topologies and different number of nodes.

In our WSN simulation system, every node detects the physical phenomenon and sends back to the sink node the data packets. We suppose that the sink node is more powerful than sensor nodes. In our previous work, the sink node was stationary. In this work, we consider that the sink is mobile. We analyse the performance of the network in a fixed time interval. This is the available time for the detection of the phenomenon and its value is application dependent.

Proposed network simulation model is shown in Fig. 1. In our work, for simulation system implementation, we considered modelling and network stack. In this paper, we consider that a mobile sink is moving randomly in the WSN field. In Fig. 2 is shown one pattern of mobile sink path. We have implemented many routing protocols, and radio models. But in this work, we show the goodput only for AODV protocol using TwoRayGround radio model for the lattice and random topologies.

A. Sensor Nodes

In order to simulate the sensor nodes, we used the NS-2 along with the libraries of Naval Research Laboratory (NRL) [9]. These libraries model the generic physical event (temperature, pressure, sound, heat) as a mobile node which emits at a constant rate a packet of fixed size. This packet is then broadcasted over the radio medium with a certain power, by assuming that the propagation laws of the physical event are the same as the electromagnetic signal propagation. In fact, by looking at Fig. 3, we note that the event node has the same physical and network layer as the sensor node network stack.

In NS-2, we can choose two types of radio models: deterministic and random. For the deterministic model, the range of the emitted signal is constant along all directions, i.e. the coverage area is a perfect circle centred at the node position[1]. We will use this deterministic and isotropic assumption for the propagation of the natural event, although the real propagation mechanisms can be different. In general, every signal can be detected at the physical layer if its received power is greater then a threshold, $\mathrm{RX}_{\mathrm{tr}}$.

In Fig. 3, we have shown also the model of the sensor. The sensor node has two channels. In the NS-2 terminology, these channels are two distinct instances of the class representing the radio medium. One channel (channel 1) is dedicated to the communication with other neighbouring nodes, and nodes use specific routing and MAC protocols. The second channel (channel 2) is used to model the sensing operations. On this channel, the sensor node hears broadcast packets from the event node. A special routing agent called PHENOM is used. The event node has two parameters, that is the pulse rate and the radiated power.

[1]If the antenna is omni-directional.

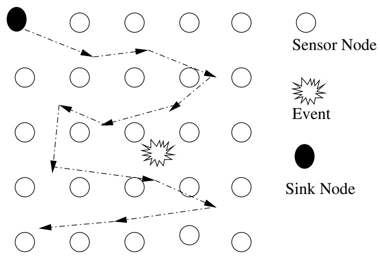

Figure 2. One pattern of mobile sink path.

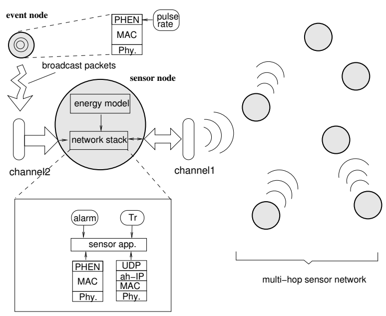

Figure 3. Sensor model.

On the sensor side, we can set a lot parameters. For example, we can set the sensing range of the sensor by changing the threshold at the physical layer of the channel used for receiving packets of the event node. We can also set an alarm variable, which is the time during which the sensor remains active. If the alarm time-outs, the sensor goes into an inactive zone, and no more (data) packets are being sent. The sensor node can use a number of routing and transport protocols as well. However, we will use the UDP protocol.

B. Topologies

For the physical layout of the WSN, two types of topologies has been studied so far: random and lattice topologies. In the former, nodes are supposed to be uniformly distributed, while in the latter one nodes are vertexes of particular geometric shape, e.g. a square grid. For lattice topology, 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 (the node degree D) is 4. Nodes at the borders have $D = 2$.

In the case of random networks, we suppose that the coordinates in the Euclidean plane of every sensor are random variables uniformly distributed in the interval $[0, L] \times [0, L]$. Snapshots of lattice and random networks generated in simulations are shown in Fig. 4 and Fig. 5, respectively.

C. Radio Models

In order to simulate the detection of a natural event, we used the libraries from Naval Research Laboratory (NRL) [9]. In this framework, a phenomenon is modelled as a wireless mobile node. The phenomenon node broadcasts packets

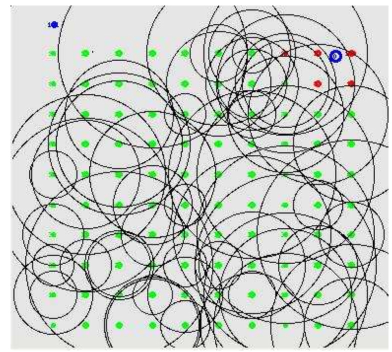

Figure 4. An example of lattice network.

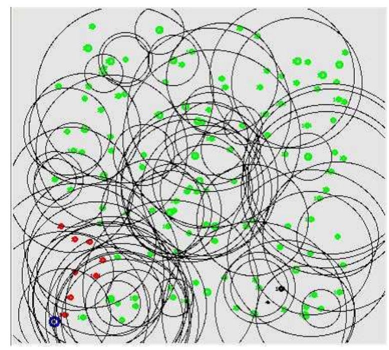

Figure 5. An example of random network.

with a tunable synchrony or pulse rate, which represents the period of occurrence of a generic event[2]. 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 sink by means of a particular routing protocol.

We assume that the MAC protocol is the IEEE 802.11 standard. This serves to 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 threshold, γ. This threshold depends on the hardware[3]. 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 $f = 916\text{MHz}$ and a data rate of 34KBaud, we have a threshold (or receiver sensitivity) $\gamma|_{dB} = -118\text{dBm}$ [10]. The calculation of the phenomenon range is not yet optimized and the phenomenon propagation is assumed to follow the propagation laws of the radio signals. In particular, the emitted power of the

[2]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.

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

phenomenon is calculated according to a TwoRayGround propagation model [11]. The received power P_r at a certain distance d is the same along all directions in the plane[4]. For example, in the case of Line Of Sight (LOS) propagation of the signal, the Friis formula predicts the received power as:

$$P_r(d) = P_t - \beta \quad (\mathrm{dB}), \qquad (1)$$
$$\beta = 10 \log \left(\frac{(4\pi d)^2 L}{G_t G_r \lambda^2} \right)$$

where G_r and G_t are the antenna gains of the receiver and the transmitter, respectively, λ is the wavelength of the signal, L the insertion loss caused by feeding circuitry of the antenna, and β is the propagation pathloss. For omni-antennas, $G_R = G_t = 1$. The signal decay is then proportional to d^2. A more accurate model is Two-Ray-Ground model, where in addition to the direct ray from the transmitter towards the receiver node, a ground reflected signal is supposed to be present. Accordingly, the received power depends also on the antenna heights and the pathloss is:

$$\beta = 10 \log \left(\frac{(4\pi d)^4 L}{G_t G_r h_t h_r \lambda^2} \right) \qquad (2)$$

where h_r and h_t are the receiver and transmitter antenna heights, respectively. The power decreases faster than Eq. (1). The formula in Eq. (2) is valid for distances $d > d_c$ (d_c is the distance threshold of signal LOS propagation), that is far from the transmitting node.

D. Energy Model

The energy model concerns the dynamics of energy consumption of the sensor. A widely used model is as follows. When the sensor transmits k bits, the radio circuitry consumes an energy of $kP_{Tx}T_B$, where P_{Tx} is the power required to transmit a bit which lasts T_B seconds. By adding the radiated power $P_t(d)$, we have:

$$E_{Tx}(k, d) = kT_B \left(P_{Tx} + P_t(d) \right).$$

Since packet reception consumes energy, by following the same reasoning, we have:

$$E(k, d) = kP_{Tx}T_B + kT_B P_t(d) + kP_{Rx}T_B \qquad (3)$$

where P_{Rx} is the power required to correctly receive (demodulate and decode) one bit.

E. Routing Protocols

We have implemented in our simulation system AODV, DSR, DSDV and OLSR routing protocols [12]. However, in this work, we consider only AODV protocol.

The AODV is an improvement of DSDV to on-demand scheme. It minimize the broadcast packet by creating route only when needed. Every node in network maintains the route information table and participate in routing table exchange. When source node wants to send data to the destination node, it first initiates route discovery process. In this process, source node broadcasts Route Request (RREQ) packet to its neighbors. Neighbor nodes which receive RREQ forward the packet to its neighbor nodes. This process continues until RREQ reach to the destination or the node who know the path to destination. When the intermediate nodes receive RREQ, they record in their tables the address of neighbors, thereby establishing a reverse path. When the node which knows the path to destination or destination node itself receive RREQ, it send back Route Reply (RREP) packet to source node. This RREP packet is transmitted by using reverse path. When the source node receives RREP packet, it can know the path to destination node and it stores the discovered path information in its route table. This is the end of route discovery process. Then, AODV performs route maintenance process. In route maintenance process, each node periodically transmits a Hello message to detect link breakage.

F. Event Detection and Transport

For event detection and transport, we use the data-centric model similar to [13], 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. The transport used is a UDP-like transport. The sensor node transmits data packets reporting the details of the detected event at a certain transmission rate.

The setting of T_r depends on several factors such as the quantization step of sensors, the type of phenomenon, and the desired level of distortion perceived at the sink. In [14], the authors used 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 in order to reliably detect the event, then whenever the sink receives a number of packets less than the event-reliability, it can instruct sensor nodes to use a higher T_r. This instruction is piggy-backed in dedicated packets from the sink. 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.

III. Goodput Metric

For evaluation purpose, we use the goodput as a metric. The goodput is defined at the sink node, and it is the received packet rate divided by the sent packets rate. Thus:

$$G(\tau) = \frac{N_r(\tau)}{N_s(\tau)} \qquad (4)$$

[4]We are considering 2D networks, but similar results hold also in the more general case of tridimensional networks.

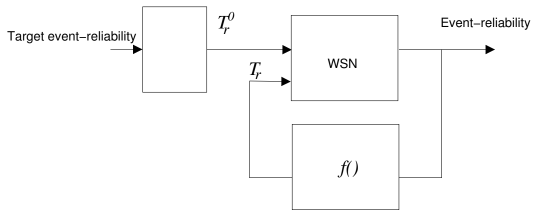

Figure 6. Representation of the transport based on the event-reliability.

Table I
SETTINGS OF THE SENSOR NODES.

Eergy Parameters	
Initial Energy	$E_I = 7.5J(= 2.4 \cdot 3(\text{mAhV}))$
Transmitted Power	$P_{Tx} = 0.660(\text{W})$
Received Power	$P_{Rx} = 0.395(\text{W})$
Sensing Energy	$1\mu(\text{J})$
Other Parameters	
Reporting Rate	$T_R = 0.1 \div 1(\text{Kpps})$[1]
UDP Packet Size	100 (bytes)

[1] packet per seconds

Table II
TOPOLOGY SETTINGS.

Lattice	
Step	$d = \frac{L}{\sqrt{N-1}}$ m
Service Area Size	$L^2 = (800\text{x}800)\text{m}^2$
Number of Nodes	$N = 64, 100, 256$
Transmission Range	$r_0 = d$
Random	
Density(nodes/m^2)	$\rho \in \{25 \cdot 10^{-6}, 2 \cdot 10^{-4}\}$
Transmission Range(m)	$r_0 = 180$

Table III
RADIO MODEL AND SYSTEM PARAMETERS.

Radio Model Parameters	
Path Loss Coefficient	$\alpha = 2.7$
Variance	$\sigma^2_{\text{dB}} = 16\text{dB}$
Carrier Frequency	916MHz
Antenna	omni
Threshold (Sensitivity)	$\gamma = -118\text{dB}$
Other Parameters	
Interface Queue Size	50 packets
Detection Interval τ	30s

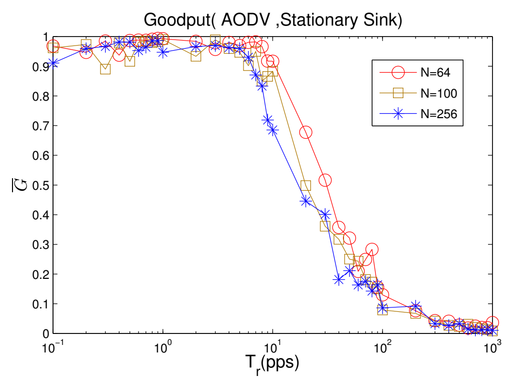

Figure 7. Goodput for stationary sink.

where $N_r(\tau)$ is the number of received packets at the sink, and the $N_s(\tau)$ is the number of packets sent by sensor nodes which detected the phenomenon. These quantities are computed in a time interval of τ seconds. Since we are using an event-reliability approach for the congestion control, this metric can be considered as a measure of the received transmission rate at the monitoring node. The monitoring node can require a lower distortion by means of dedicated messages which instruct sensor nodes in how to adjust reporting rate or other sensing parameters. This adjustment will in turn affect the congestion level within the network.

IV. SIMULATION RESULTS

In this section, we present the simulation results of our proposed WSN. We simulated the network by means of NS-2 simulator, with the support of NRL libraries. In this work, we simulated two patterns considering stationary sink and mobile sink. For AODV routing protocol, the sample averages of Eq. (4) are computed over 20 simulation runs, and they are plotted from Fig. 7 to Fig. 9.

In Table I, Table II and Table III, we summarise the values of parameters used in our WSN. The power values concern the power required to transmit and receive one bit, respectively. They do not refer to the radiated power at all. This is also the energy model implemented in the widely used NS-2 simulator.

The results for lattice topology are shown in Fig. 7 and Fig. 8. We can clearly distinguish three operating zones. For low values of T_r, the network is uncongested. From a particular value of T_r ($\sim$ 10pps), the goodput decreases abruptly, because the network has reached the maximum capacity. For $T_r > 100$pps, the goodput is very low, because of contention and congestion.

The results of random topology are plotted in Fig. 9. The goodput of random topology is better than the case of lattice topology when the number of nodes is less than 100. Otherwise, when the number of nodes is 256, the average goodput is approximately the same with 100 nodes. The explanation of this effect is not simple, because it is intermingled with the dynamics of MAC and routing protocols. However, intuitively we can say that the on-demand routing protocols are affected by the presence of the mobile sink. It is worth noting that AODV and other protocols cannot use unidirectional links. On the other hand, exploiting such links is possible but the performance gains are quite low. Thus, the routing protocol spends most of the time in the searching of a bi-directional path. Thus, given a fixed detection interval, N_r can be much lower than its value in the case of the lattice topology, where the discovered paths do not change over time[5]. This fact may not affect the performance of the WSN, because it depends on the requirements of the application. For high values of N, the augmented interference level and the path instability seem to be predominant [15].

[5]This is true if we do not count the reliability of nodes, i.e. the probability of failure of sensor nodes.

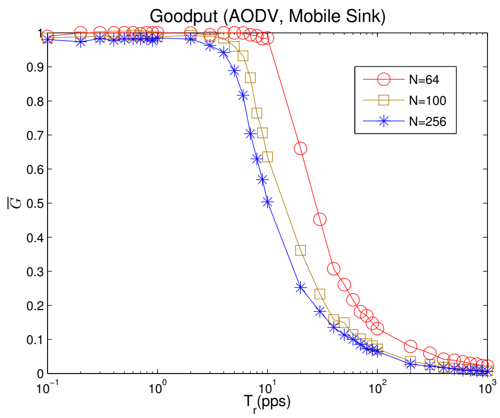

Figure 8. Goodput for mobile sink.

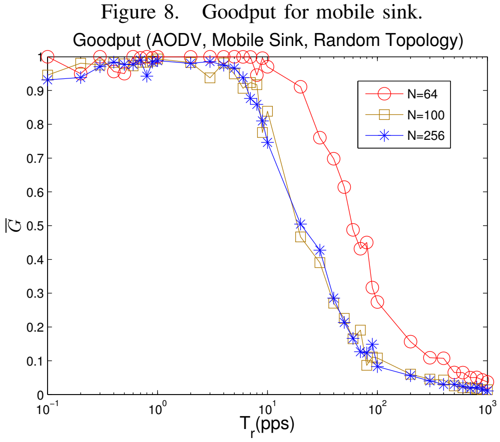

Figure 9. Goodput for mobile sink with random topology.

V. Conclusions

In this paper, we presented a simulation system for WSNs. We implement our system as a multi-modal system. We used the goodput metric and evaluated the performance of WSNs for AODV and TwoRayGround model considering different topologies and number of nodes. We investigated the performance of WSNs in the case when the sink node moves.

We compared the simulation results for two cases: when the sink node is mobile and stationary. From the simulation results, we found that for both the stationary and mobile sinks, the goodput decreases with the increase of number of sensor nodes. However, in the case of stationary sink, the gooput is unstable. In the case of mobile sink, the goodput is stable and better than in case of stationary sink, especially when the number of nodes is increased.

In the future, we would like to carry out more extensive simulations for multi-mobile sinks, different protocols and different radio models.

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