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Effects of Signaling on the Performance of Directed Diffusion Routing Protocol

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Abstract**—**In an original directed diffusion routing protocol, a sink requests sensing data from a source node by flooding interest messages to the network. Then, the source finds the sink by sending exploratory data messages to all nodes that generate incoming interest messages. This protocol signaling can cause heavy traffic in the network, an interference of the radio signal, collisions, great energy consumption of sensor nodes, etc. According to this research problem, this paper investigates the effect of sending interest and exploratory data messages on the performance of directed diffusion routing protocol. We demonstrate the research problem occurred from employing directed diffusion protocol in mobile wireless environments. For this purpose, we perform a set of experiments by using NS2 (network simulator 2). The radio propagation models; Two-ray ground reflection with and without shadow fading are included to investigate the effect of signaling. The simulation results show that the number of times of sent and received protocol signaling in the case of sending interest and exploratory data messages are larger than the case of sending other protocol signals, especially in the case of shadowing model. Additionally, the number of exploratory data message is largest in one round of the protocol procedure.

Keywords**—**Directed diffusion, Flooding, Interest message, Exploratory data message, Radio propagation model.

I. Introduction

DIRECTED diffusion routing [1] is a new paradigm of routing protocol for wireless sensor networks [2]. It is a data-centric routing scheme, and sensing data is named using attribute-value pairs. Directed diffusion routing establishes a route by employing the interest and the exploratory data messages. A sink or a base-station requests data from a source by flooding the interest message to a network. When the interest message reaches the source, the sink confirms the possible routes by sending the exploratory data message to all neighbors that generate incoming the interest messages. The intermediate nodes do the same. However, this routing approach can cause heavy traffic, the packet collision, an interference of the radio signal, and great energy consumption of the sensor nodes, especially in dense wireless sensor networks. In the research literature, the problem about the signaling overhead in directed diffusion routing protocol is continuously addressed. References [3]-[5], [16], and [17] study how to reduce the interest message by modifying an original directed diffusion. References [6] and [7] investigate how to decrease the exploratory data message on directed diffusion routing. In [8], the reduction of the interest and the exploratory data messages is proposed. To the best of our knowledge, there is no work in the research literature has directly demonstrated the effects of protocol signaling on the performance of an original directed diffusion routing. How the protocol signaling is generated in the routing algorithm is still not explored sufficiently.

According to this research gap, the objective of this study is to demonstrate the research problem occurred from employing an original directed diffusion protocol in mobile wireless environments through the extensive simulation. We investigate the effect of sending and receiving protocol signaling on the performance of directed diffusion routing. Additionally, the different radio propagation models; Two-ray ground reflection and shadowing models are also included to study the effect of signaling. The simulation results indicate that the protocol signaling in the case of sending and receiving interest and exploratory data messages are higher than the case of other protocol signaling. The number of exploratory data message is largest if one round for sending and receiving each protocol signaling of the directed diffusion procedure is considered. Both the numbers of interest and exploratory data messages are significantly increased in the dense mobile wireless sensor networks. In addition, the number of protocol signaling in the case of shadowing model is higher than the case of the two-ray ground reflection model. This is because the multipath fading effect reduces the successful of path setup; the routing establishment process is more repeated.

The remainder of this paper is organized as follows. In Section II, we introduce the directed diffusion routing protocol. In Section III, we describe the simulation models; the mobility model and the radio propagation models are presented. Section IV presents the simulation design. In Section V, the simulation results and discussions are detailed. Finally, Section VI concludes this paper

II. Directed Diffusion Routing Protocol

Directed diffusion [1] is a data-centric routing protocol for wireless sensor networks. Sensing data collected by a sensor node is named by attribute-value pairs. A node requests sensing data by sending an interest for named data. Data matching the interest is sent back toward that node. Intermediate nodes can cache and transform data. The node requesting sensing data is called a sink. The node detecting data is called a source. The routing mechanisms of directed diffusion routing protocol are illustrated in Fig. 1. In Fig. 1 (a), the sink requests sensing data from the source by broadcasting the *interest message* to the network (interest propagation). This message contains a description of the event in which the

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sink is interested. When the intermediate nodes receive this message, they will setup a *gradient* (direction state in each node that receives the interest) to the neighbors from which they heard the interest. In Fig. 1 (b), when the interest message reaches the source (data matching is found), the initial data message from the source is marked as *exploratory data* and it sends to all neighbors for which it has matching gradient. In Fig. 1 (c), the sink begins the path reinforcement and sending a *reinforcement* message to only one of its neighbors, namely the one where it heard the exploratory data first. Intermediate nodes which receive the reinforcement message do the same. Finally, when the source receives the reinforcement message, it starts to send *data* as shown in Fig. 1 (d).

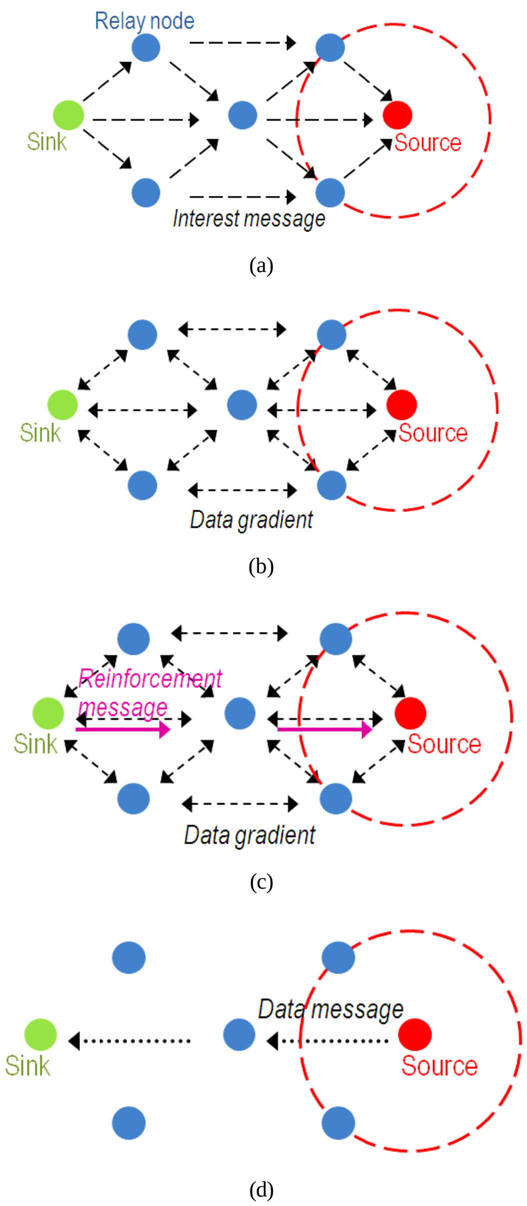


Fig. 1 Directed diffusion routing mechanism; (a) Interest propagation, (b) Exploratory data, (c) Reinforcement path, and (d) Data delivery along the reinforcement path

III. Simulation Model

A. Mobility Model

The mobility model [9], [10] is employed to indicate the moving pattern of the sensor nodes. It specifies how the direction and the speed of the mobile nodes are changed. To set the environment close the reality in the simulation, the movement of the sensor node must be considered. This is because both the radio signal propagation and the network connectivity in mobile wireless sensor networks directly affect the routing mechanism. In this work, we select the random waypoint model [9], [10] because this model is simple to study the performance of mobile wireless sensor networks. In random waypoint model from NS2 [11], the node randomly selects a destination and moving toward it with a speed selected randomly in ranging from [V_{min}, V_{max}] by the uniform distribution or the normal distribution. V_{min} and V_{max} are the minimum and maximum allowable velocities. After reaching the certain destination, the node will stop for the duration of the pause time. After this duration, each sensor node again chooses a random speed and a destination. This process is repeated until the simulation time expires.

B. Radio Propagation Model

The radio propagation has a great impact on the efficiency of the routing mechanisms. In general, the radio signal changes rapidly and randomly. Thus, this effect must be considered in the exploration and the evaluation of routing algorithm. The difference radio propagation models can cause the difference effects on the performance of routing protocols. To investigate the impact of the radio propagation models for signaling overhead effect on directed diffusion routing, we consider two radio propagation models that implemented in NS2: two-ray ground reflection [12], [13] and shadowing models [12], [14], [15].

Two-ray ground reflection model: The two-ray ground reflection model is the large-scale propagation model. This model is considered both the direct path (line of sight) and the ground reflection path; the received energy at the receiver is the sum of both. The received power at the distance d is calculated by (1).

$$P_r(d) = (P_t * G_t * G_r * h_t^2 * h_r^2) / d^4 * L \tag{1}$$

where $P_r(d)$ is the received signal power at the distance d, P_t is the transmitted signal power, G_t and G_r are the antenna gains of the transmitter and the receiver respectively, h_t and h_r are the height of the transmit and receive antennas respectively, and L is the system loss.

Shadowing model: The two-ray ground reflection model calculates the received power as a function of distance. It represents the communication range as an ideal circle. This model is known to resemble reality quite poorly. In reality, the received power at the certain distance is a random variable due to the multipath propagation effect or the fading effect. A more widely used radio propagation model is a shadowing model. The shadowing model takes into account channel fading. The advantage of the shadowing model is that it replaces the ideal circle model to the statistical model where the nodes near the edge of the circle can only probabilistically communicate. This model includes a probabilistic term as part of the calculation of the received signal power. It can be written by (2).

$$[P_r(d)/P(d_0)]_{dB} = 10\beta \log(d/d_0) + X_{dB} \quad (10)$$

where $P_r(d)$ is the mean received power at the distance d as computed relative to a reference power $P_r(d_0)$ at the distance d_0. β is the path loss exponent depending on the characteristic of environments, and X_{dB} is a Gaussian random variable with zero mean and standard deviation σ_{dB}, called the shadowing deviation. In our simulation, we use the shadowing model with β = 4 and σ_{dB} = 4 (outdoor environments).

IV. Simulation Design

We use NS2 version 2.33 to simulate the directed diffusion routing protocol. We include the mobility model as the random waypoint model and the different radio propagation models to investigate the effects of protocol signaling during the routing establishment process. Small and large scales of network sizes are examined in this study. In the small scale network, 20 nodes are studied. In the large scale network, 100 nodes are studied. There are one sink and one source in all scenarios. The sink node's location is fixed at x = 70 m and y = 70 m, and the source node's is fixed at x = 620 m and y = 620 m. All sensor nodes, except the source and the sink, are randomly located and moving in a 670 m * 670 m sensor field. Table I shows all parameters used for the simulation.

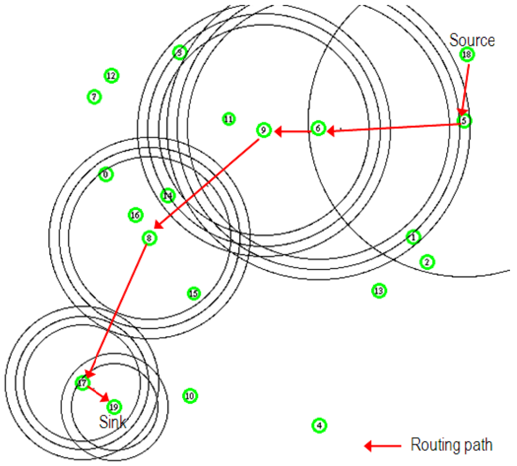
For the performance evaluation, we measure the number of times of sent and received protocol signaling to analyze the effects of sending and receiving protocol signaling of directed diffusion routing. This metric measures the total number of times of sent and received interest, exploratory, reinforcement and data messages. Thus, it indicates all transmission activities in the network.

TABLE I
Parameters Used for the Simulation

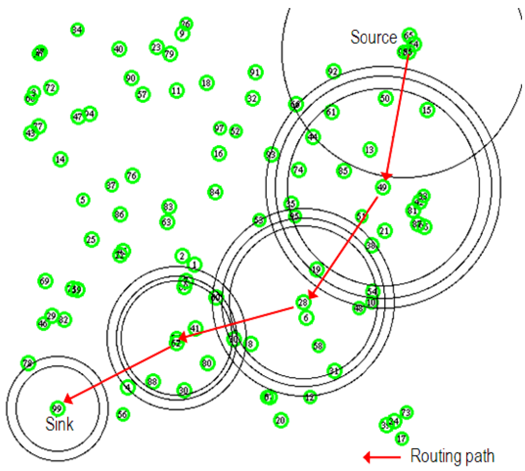
Parameters	**Values and Units**
Simulation times	70 s
Network sizes	20 and 100 nodes
Dimension of the topology	670 m*670 m sensor field
Sink and source node's locations	Sink node's location is x = 70 m and y = 70 m Source node's location is x = 620 m and y = 620 m
Mobility speed	Uniformly distributed between 0.1- 2.0 *m/s* [9].
Transmission range	250 m
RXThersh and *CSThresh*	3.65262×10^{-10} Watt and 1.55900×10^{-11} Watt for two-ray ground reflection model [6] 1.08200×10^{-14} Watt and 4.61817×10^{-16} Watt for shadowing model [6]
Routing protocol	Directed diffusion
MAC	IEEE 802.11 [1]

V. Simulation Results and Discussions

Fig. 2 shows an example of the routing path between the sink and the source in the small and large scales of the network sizes. We can see these results by the network animation tool in NS2.



(a)



(b)

Fig. 2 The routing path between the sink and the source; (a) the 20 nodes scenario and (b) the 100 nodes scenario

Figs. 3-6 present the number of times of sent and received protocol signaling; interest, exploratory data, reinforcement, and data messages. The simulation results show that, at the end of the simulation the number of times of sent and received protocol signaling in the case of the interest message is highest (interest > exploratory data > data > reinforcement) in the both cases of two-ray ground reflection and shadowing models. When we consider both models in only one phase (the red circle in the figure indicates the one round of the protocol procedure), the number of times of sent and received exploratory data message is higher than other messages (exploratory data > interest > data > reinforcement). Note that the number of signaling is higher when the number of node in the sensor field is increased.

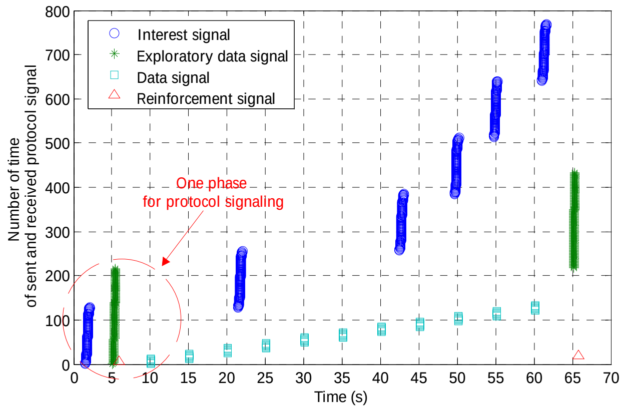


Fig. 3 Number of times of sent and received protocol signaling in the case of 20 nodes scenario with two-ray ground reflection model

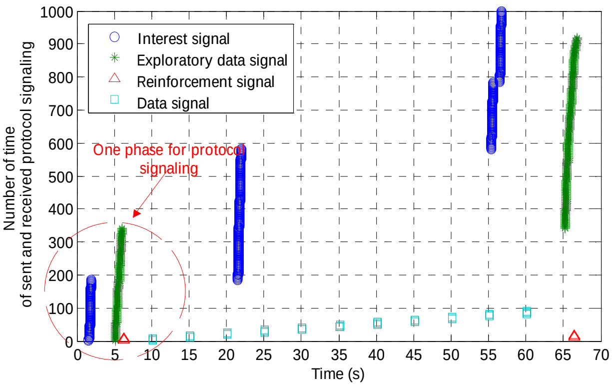


Fig. 4 Number of times of sent and received protocol signaling in the case of 20 nodes scenario with shadowing model

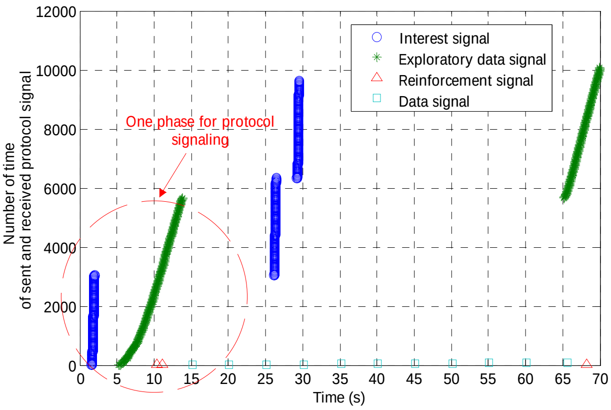


Fig. 5 Number of times of sent and received protocol signaling in the case of 100 nodes scenario with two-ray ground reflection model

Fig. 7 compares the total number of time of sent and received each protocol signaling in one phase of the protocol procedure with the two-ray ground reflection and shadowing models. These results indicate that the number of time of sent and received exploratory data message is highest. The reason can be explained here. In the directed diffusion routing mechanism, the sink requests data from the source by flooding interest messages to the network. Then, the source finds the sink by sending exploratory data messages to all nodes that matches the interest. The exploratory data messages are propagated to all nodes that generate incoming interest messages; this approach can cause higher number of sending and receiving exploratory data than other messages.

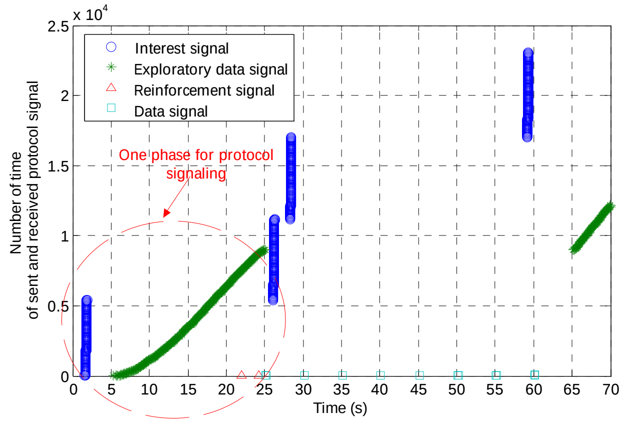
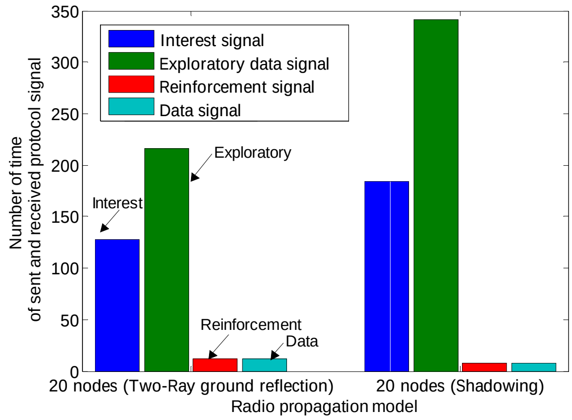


Fig. 6 Number of times of sent and received protocol signaling in the case of 100 nodes scenario with shadowing model

To extend the previous discussion as explained in Fig 7, the description of sending protocol signaling in directed diffusion is illustrated in Fig. 8. We assume that the sink and the source are node IDs 0 and 4, respectively. Node IDs 1, 2, and 3 are the relay nodes. We describe only the routing process at these relay nodes. In the interest propagation stage, the sink sends the interest message to node ID 1. Then, node ID 1 forwards the interest message by the flooding technique to node IDs 2 and 3 only in one time. Node ID 2 forwards the interest message to node IDs 1 and 3 in one time, and node ID 3 also forwards the interest message to node IDs 1 and 2 in one time. Thus, the total number of times of sent the interest message by the relay nodes is 3 times. In the exploratory data propagation stage, node ID 3 must send the exploratory data message to node IDs 1 and 2 in two times. The relay node IDs 2 and 3 do the same approach. Thus, the total number of time of sent the exploratory data message by the relay nodes is 6 times. In the reinforcement propagation stage, the sink sends the reinforcement message to node ID1. Node ID 1 selects only one of its neighbors (node IDs 2 or 3) to send the reinforcement message. Node IDs 2 and 3 do the same approach to forward this message. Thus, the total number of time of sent the reinforce message by the relay nodes is 2 times. For the data propagation stage, we assume that the source sends its sensing data to the sink through node ID 3. Node ID 3 delivers the data message along the reinforcement path. Thus, the total number of time of sent data message by the relay nodes is 2 times.



(a)

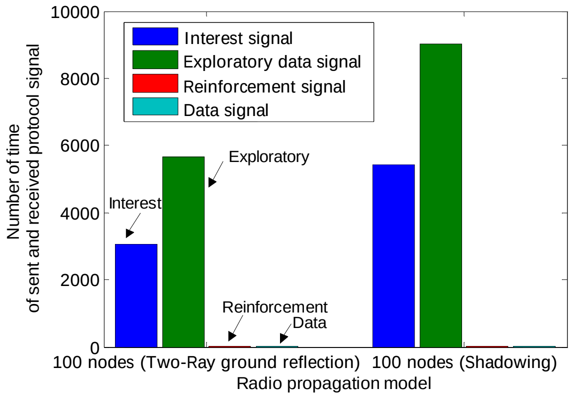


Fig. 7 The total number of times of sent and received each protocol signaling in one phase of the protocol procedure vs. the radio propagation models; (a) in the case of 20 nodes scenario and (b) in the case of 100 nodes scenario

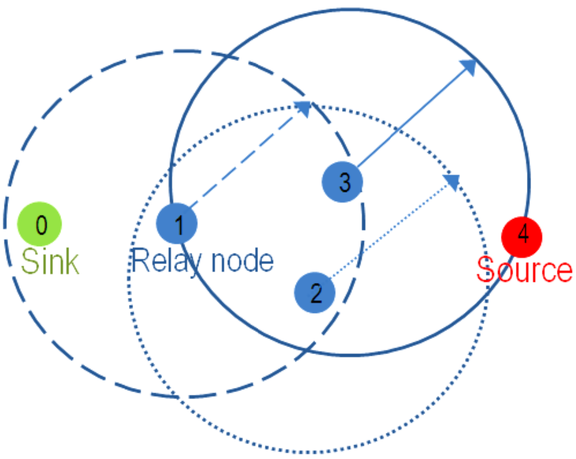


Fig. 8 An illustrated scenario to describe how the nodes send and receive the protocol signaling

Fig. 9 shows that the number of times of sent and received the interest message at the end of the simulation time is higher than the number of times of sent and received other messages. According to the directed diffusion algorithm, the interest messages are often send and received than exploratory data messages for monitoring the route status. Consequently, the number of times of sent and received interest message is highest. Additionally, although the data messages are often sent and received, but there are small numbers of sensor nodes in the selected route sending and receiving the data message. Therefore, the number of data messages relates the sampling interval of the source and the simulation time.

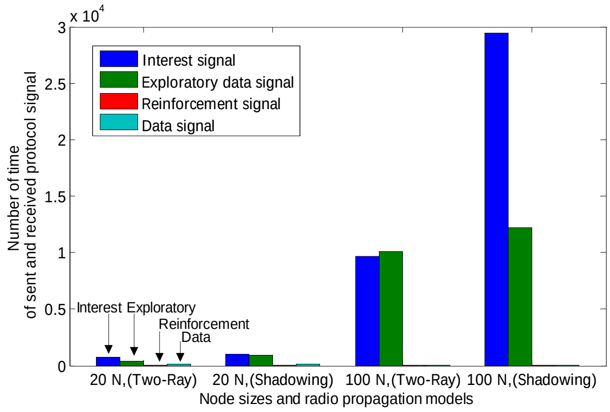


Fig. 9 The total number of times of sent and received each protocol signaling at the end of the simulation time in the case of 20 and 100 nodes scenarios with two-ray ground reflection and shadowing models

The number of time of sent and received all protocol signaling in Figs. 4 and 6 with shadowing model is higher than the same metric as in Figs. 3 and 5 (two-ray ground reflection model). The reason why the fading effect leads to the higher number of transmissions is discussed here. NS2 uses the radio propagation model to calculate the received power of the radio signal for all receiving nodes. If the received power level is higher than the received threshold (*RXThersh*), the packet is correctly received. If the received power level is between the received threshold and carrier-sense threshold (*CSThresh*), the packet is received with an error. The packets that experience the received power level below the carrier sense threshold are not detected by the receiver. In the two-ray ground reflection model, the sensor nodes always successfully receive packets when they are in the radio communication range of the sending node. On the other hand, any nodes moving farther away the edge of the radio range cannot receive the packets from the sender. Unfortunately, this phenomenon does not occurred in physical environments. In reality, the received power level of a sensor node at a certain distance is a random variable due to multipath and fading effects. For the case of shadowing-model, there is more chance that the nodes do not completely receive the interest or the exploratory messages due to fading effects (*CSThresh* < *received power level* < *RXThersh*). Thus, the routing establishment process is usually unsuccessful. The nodes will try to re-establish the route by sending the interest, exploratory, and reinforcement messages until it success. As a result, the protocol signaling in the case of shadowing model is increased larger than the case of the two-ray ground reflection model.

VI. Conclusion

The effect of sending and receiving protocol signaling on the performance of directed diffusion has been investigated in this paper. We demonstrate that employing the different radio propagation models in the simulation study can help to better understand the effect of protocol signaling. The two-ray ground reflection model is not sufficient in investigating the protocol signaling effects on routing; the shadowing model is more appropriate. The shadow fading causes high number of times of sent and received protocol signaling due to the unsuccessful transmission of the packets. This problem becomes worse in the dense mobile wireless sensor networks. Additionally, our findings indicate that the protocol signaling as the interest and exploratory data messages are larger than the case of other protocol signaling. The number of exploratory data message is highest in one round of the directed diffusion procedure. For the future work of our research, to resolve these high protocol signaling (interest and exploratory data messages) in directed diffusion routing is required because it can help to reduce the packet collision, an interference of the radio signal, and the energy consumption of the sensor nodes.

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