Evaluating the Impact of Next Node Selection Criteria on Quality of Service Dynamic Routing

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Abstract—**Dynamic routing is considered an attractive solution for many network applications such as monitoring and tracking. In dynamic routing the path between the source and the destination can change dynamically following the network conditions. Next node selection criteria can have a great impact on the selection of each path and as a consequence on the network performance. Moreover, each network application may have different Quality of Service (QoS) requirements. In this paper, we examine the impact of the next node selection criteria on the network performance. Three routing protocols with different approaches along with their routing algorithms are presented. To examine the performance of each approach a discrete event simulator is used. It is shown that the selection criteria should be carefully designed following the QoS requirements of the network application. Furthermore, the obtained performance results can be used as an indicator of the appropriateness of a dynamic protocol for a variety of applications.**

I. INTRODUCTION

Quality of Service (QoS) routing tries to satisfy application performance requirements by selecting routes with sufficient resources for the selected QoS parameters. In recent years, a lot of effort has been devoted to improve the performance of wireless ad hoc networks, in terms of power consumption and packet latency. One promising approach is to allow the relay nodes to cooperate, thus using the spatial diversity to increase the capacity of the system. However, one of the main drawbacks of this approach is that it requires information exchange between the nodes, which introduces overhead and increases the complexity of the receivers. A simpler way of exploiting the spatial diversity is opportunistic routing, also called opportunistic forwarding [1].

In opportunistic routing, intermediate nodes collaborate to packet forwarding in order to achieve high throughput in the face of lossy communication links. Opportunistic routing tries to overcome the drawback of unreliable wireless links by taking advantage of the broadcast nature of the wireless medium. One transmission can be overheard by multiple nodes. As a consequence, a cluster of nodes can serve as relay candidate set and one node of this set will finally forward the packet. As it can be inferred, the task of routing in an opportunistic forwarding protocol is crucial for the network performance, [2], [3] and it can be divided into different steps.

The task of routing includes the next node selection process and the route selection process towards the destination. Traditional routing protocols usually perform best path routing. In this approach, the best path between the source and the destination is chosen, in line with the application requirements. This path is fixed before the transmission starts. However, the highly dynamic and lossy nature of wireless medium causes frequent transmission failure which leads to retransmissions and, as a result, waste of network resources, or even system breakdown. To overcome these problems, opportunistic routing tries to discover multiple paths toward the destination and to forward the packets over different paths, according to network conditions. In contrast with traditional end-to-end multi-hop routing, opportunistic routing is a dynamic approach that selects the communication paths according to the network conditions during the communication time.

The key issues in the design of any opportunistic routing scheme are [4]:

- the forwarder set selection,
- the prioritization of the forward set and
- the avoidance of duplicate transmissions.

In this work, we examine the effects of different selection criteria on the forward set prioritization and consequently on the network performance. Three dynamic routing approaches are presented along with their routing algorithm and simulation results. The approaches are compared in terms of energy consumption, delivery ratio and average packet latency. The simulation results show that the selection criteria have a high impact on the performance of a dynamic multi-path routing scheme. As a consequence, different selection criteria can be used for different network applications.

The rest of this paper is organized as follows: The related work is reviewed in Section II whereas system models are presented in Section III. In Section IV, three different dynamic routing approaches are described in details and the performance evaluation and simulation results are provided in Section V. Finally, conclusions are drawn in Section VI.

II. RELATED WORK

The first opportunistic routing has been introduced in [1]. In Extremely Opportunistic Routing (ExOR), the senders broadcast a number of packets. Each packet contains a list of the potential nodes that can forward it. This list is prioritized according to their proximity to the destination. In ExOR, the Expected Transmission count metric (ETX) was used which

is based on the distance between the node and the destination. One of the main drawbacks of ExOR is that the forwarding paths can easily diverge. Nodes on different paths may not hear from each other and forward the same packet. Consequently, this will lead to duplicate forwarding. In [5], the authors show how crucial the routing metric of an opportunistic routing can be. They develop a new routing metric. Expected any-path transmissions (EAX) captures the expected number of any-path transmissions needed to successfully deliver a packet between two nodes under opportunistic routing.

The idea of ExOR has since inspired a number of interesting extensions. MAC-Independent Opportunistic Routing and Encoding Protocol (MORE) [6], enhances ExOR to further increase the spatial reuse in a single flow from source to destination via intra-flow network coding. Geographical Opportunistic Routing (GeOpps) [7], for vehicular networks tries to exploit the available information in modern vehicles along with an opportunistic routing in order to select the next carrier efficiently. In this approach, the location information of each node is important. Similarly in [8], a Geographic Random Forwarding (GeRaF) technique was proposed that makes use of the location information for the selection of the next relay node. In [9], Simple Opportunistic Adaptive Routing (SOAR) was introduced. SOAR incorporates an adaptive forwarding path selection along with a priority timer-based forwarding, local loss recovery and adaptive rate control to achieve high throughput to the current network conditions. In [10], an Energy Aware Opportunistic Routing (EAOR) is introduces. EAOR is designed for Wireless Sensor Networks (WSNs) and it uses opportunistic routing principles in order to maximize network lifespan without increasing the packet delay. A cooperative opportunistic routing scheme was introduced in [11]. In Cooperative Opportunistic Routing Scheme in Mobile Ad Hoc Networks (CORMAN), the nodes in the network use a lightweight proactive source routing protocol to determine a list of intermediate nodes that the data packets should follow en route to the destination. In [2], the performance of different opportunistic routing schemes in WSNs was examined.

A number of QoS routing protocols with distinguishing features have been proposed in recent years. In [12], a QoS routing scheme for wireless multimedia ad hoc network was presented while in [13] a statistical QoS routing was introduced. A fully distributed scheduling scheme for video streaming over multi-channel multi-radio multi-hop wireless networks was presented in [14]. In [15], an energy-aware MAC and routing mechanisms was designed specifically for WSNs to reduce energy consumption and provides QoS guarantees. In [16], a detailed survey on QoS routing protocols and MANETs was presented. A comparative study of QoS routing protocols in MANETs can also be found in [17].

In this work, we consider a basic categorization of opportunistic protocols. For each category, we present the routing algorithm and the corresponding performance of the protocol. Finally we carry out a discussion and we propose potential applications for each routing protocol.

III. SYSTEM MODELS

This section outlines basic system models of the opportunistic routing protocols. The opportunistic routing principles will be described, followed by the packet relay mechanism and the link model. At the end of this section, there is a classification of the opportunistic routing approaches.

A. Opportunistic Routing Principles

In opportunistic routing, for every packet transmission, a cluster of nodes serves as candidate set, but only one node will be the relay node. This relay node will finally forward the packet. This selection process is crucial and can affect the entire routing path. Opportunistic routing can change both the relay node and the number of the possible paths toward the destination in order to improve the performance. Instead of choosing a single route ahead of time, the path is determined as the packet moves through the network, based on which node receives each transmission.
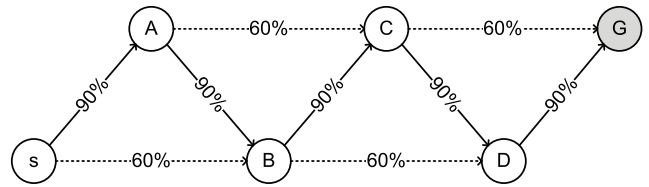

Fig. 1: Example of path-based opportunistic forwarding.

An illustrative example of the route selection and the different paths toward the destination is depicted in Fig. 1. Each link *(x,y)* has a delivery probability *P(x,y)*. The links with the dots represent opportunistic links. Traditional best path routing will always choose the most reliable links, which result in the path $s \rightarrow A \rightarrow B \rightarrow C \rightarrow D \rightarrow G$, which has end-to-end delivery probability $(0.9)^5 \approx 59\%$, after 5 hops. An opportunistic routing scheme, with the restriction of 3 hops has the following paths: $s \rightarrow A \rightarrow C \rightarrow G$, $s \rightarrow B \rightarrow D \rightarrow G$ and $s \rightarrow B \rightarrow C \rightarrow G$. The first path has successful delivery probability of:

$$P_{sA} \times (1 - (1 - P_{AC} \times P_{CG})) =$$
$$0.9 \times (1 - (1 - 0.6 \times 0.6)) = 32.4\% \tag{1}$$

The other two paths have successful delivery probability of:

$$P_{sB} \times (1 - (1 - P_{BD} \times P_{DG}) \times (1 - P_{BC} \times P_{CG})) =$$
$$0.6 \times (1 - (1 - 0.54) \times (1 - 0.36)) \approx 42.3\% \tag{2}$$

The overall successful delivery ratio of the above paths is:

$$1 - ((1 - 0.324) \times (1 - 0.423)) \approx 60.9\%. \tag{3}$$

From this example, it can be inferred that an efficient node and route selection, through an opportunistic routing scheme, can improve the network performance.

B. Packet Relay Mechanism

There are four types of packets: Request To Send (RTS), Clear To Send (CTS), DATA and Acknowledgement (ACK). The RTS and CTS packets are used during the handshake process between neighbor nodes and ACKs are used for verification of DATA delivery.

When a node has a DATA packet to transmit, first it employs the RTS/CTS handshake phase. During this phase, the node can find its neighbor nodes and which of these neighbor nodes are available for immediate transmission. The node which has the DATA packet, first broadcasts a RTS packet and then it waits for time equal to T_{CTS} for CTS packets. The neighbor nodes that successfully received the RTS packet, they need to process it and if they are available, they will reply with a CTS packet. Next, these nodes will wait for the DATA packet for time T_{DATA}. The node that will be selected as the next relay node, will receive the DATA packet and will reply with an ACK packet, while the rest of the candidate nodes will go back to sleep mode.

It can be inferred from the above that, on the design of any opportunistic protocol, the different times, T_{CTS} and T_{DATA} should be carefully selected. For instance, the time to wait for a CTS packet, T_{CTS}, should be sufficient for all the nodes in the transmission range of the source node to participate, hence the minimum T_{CTS} should be:

$$Minimum \ \{ \ T_{CTS} \ \} = R \times C_0 + SIFS \qquad (4)$$

where R is the transmission range, C_0 is a constant depending on the application and $SIFS$ is the Short Interframe Space.

The timing scheme can be used to prioritize the forwarding set. For example, the source node can prioritize the candidate nodes based on the order of the reception of the CTS packets. In this case, the time that each node will reply with a CTS packet should be related with information about this node, such as its energy level [10] or its location [18].

C. Link model

When a node sends a packet to a neighbor node over a link there is a Packet Reception Ratio (PRR). To simulate a realistic channel model with Binary Phase-Shift Keying (BPSK) without channel coding, the log-normal shadowing path loss model derived in [19] was used:

$$PRR(L_f, d) = (1 - \frac{1}{2} \exp^{-\frac{\gamma(d)}{2 \times 0.64}})^{8\rho L_f} \qquad (5)$$

where L_f is the length of the frame, d is the distance between the transmitter and the receiver, $\gamma(d)$ is the Signal to Noise Ratio(SNR) and ρ is the encoding ratio.

This model also considers a number of other environmental and radio parameters, such as the log-normal shadowing variance of the environment (σ), the path-loss exponent (α) as well as the modulation and encoding schemes of the radio.

In every time slot, there can be only one packet transmission. When a packet is lost or damaged, it will be retransmitted in the next available time slot, following the routing protocol principles. An accurate and realistic channel model for opportunistic routing was introduced in [20].

D. Classification of opportunistic routing

The main feature of any opportunistic routing protocol is how to determine the forwarding set and how to assign the priority to the nodes in the set. We can classify the opportunistic protocols according to their selection criteria in the following groups:

- *Geographical protocols.* The location of the nodes in the forwarding set is crucial for those protocols.
- *Delivery-based protocols.* The paths are selected according to their reliability. The nodes are selected according to the loss probabilities of the link between the source and the candidate.
- *Probabilistic protocols.* Probabilistic selection requires no coordination among candidates and is more resilient to highly lossy and uncertain wireless environments.

In the following section we will describe an approach of each group along with its routing algorithm.

IV. DYNAMIC ROUTING APPROACHES

In this section, three approaches based on the previous classification will be introduced along with their algorithms.

A. Geographical forwarding

Geographical forwarding prioritizes the candidate nodes according to their geographical location. Nodes that are closer to the destination have higher probability to become the next relay node. In order to prioritize the nodes, one approach is the use of a backoff time $T_{backoff}$. This time can be inverse proportional to the distance between the source node, src, and the candidate node, cnd, as follows:

$$T_{backoff} = \frac{C_1}{D_{src,cnd}} + SIFS, \ D_{src,cnd} \leq R \qquad (6)$$

where C_1 is a constant related with the transmission range of each node and $D_{src,cnd}$ is the distance between the source and the candidate node defined as:

$$D_{src,cnd} = 1 + |d_{src,cnd} - d_{cnd,dst}|, \ src \neq cnd \qquad (7)$$

where $d_{src,cnd}$ is the distance between the source and the candidate node, and $d_{cnd,dst}$ is the distance between the candidate and the destination node.

As it can be inferred from Eq. 6, the closer the candidate is to the destination, the smaller the backoff time. After that time, the node will reply with a CTS. On the reception of the first CTS packet, the source node will forward DATA packet to this node and will ignore any of the following CTS packets for this DATA packet. Algorithm 1 illustrates the process.

B. Delivery-based forwarding

Delivery-based forwarding uses the PRR values to prioritize the candidate node list. On the reception of a CTS packet, the source node can extract useful information from the Received Signal Strength Indicator (RSSI) of the packet. This value can be used in Eq. 5 in order to calculate the PRR probability. According to this value, the source node can prioritize the candidate nodes.

Algorithm 1: Geographical forwarding.

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1 **if** *(isRTS(rts))* **then**
2   T_{RTS}= CalculateBackoff();
3   wait(T_{RTS});
4   Channel=ChannelSensing();
5   **if** *(Channel==IDLE)* **then**
6   SendCTS(rts.SenderNode);
7   interval=T_{DATA};
8   reason=Listen(interval);
9   **if** *(reason==DATA)* **then**
10   SendACK(DATA.SenderNode);
11   **else**
12   GoToSleepMode();
13   **end**
14   **else**
15   GoToSleepMode();
16   **end**
17 **end**

There can be different implementations of the delivery based approach. In one implementation, the source node can wait for all the candidates to reply with a CTS, and prioritize all the available links according to the PRR. In this case, the source node should have a waiting time which is related to the transmission range and the average number of neighbor nodes. However, if the network density is high, the source node will have to wait for many nodes to reply. In this case, its energy consumption increases.

Another implementation can use a threshold. The node that will reply first with a PRR value which satisfies a predefined threshold, will become the next relay node with the source node ignoring all the following CTS packets. In this second approach, the threshold should be carefully selected and it is based on the QoS requirements of the application. Algorithm 2 illustrates the process.

C. Probabilistic forwarding

Probabilistic forwarding is used in highly lossy environments. The probability which a candidate node will be chosen as a relay node is decided independently from the network conditions. In one approach of this group, the source node can wait for all the CTS packets and then randomly chose the next relay node. The main drawback of this approach is that

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Algorithm 2: Delivery-based forwarding.

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1 **if** *(isCTS(cts))* **then**
2   **if** *(cts.RSSI $\geq$ PRR.Threshold)* **then**
3   SendDATA(cts.SenderNode);
4   **else**
5   UpdatePRRvalue(cts.RSSI);
6   WaitForCTS;
7   **end**
8 **end**

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the selection criteria are completely random while the source node has to wait for all the CTS packets.

A combination of geographical and probabilistic forwarding can deliver an efficient approach. On the reception of the CTS packet from the source node, *src*, the candidate node, *cnd*, will wait for time $T_{backoff}$, as in Eq. 6, along with a random interval, hence:

$$T_{backoff} = C_1 \times D_{src,cnd} + C_2 \times rand(0,1) + SIFS, \ c \neq G \tag{8}$$

The selection of constants C_1, C_2 is also important. If $C_1 \leq C_2$, the forwarding is based more on the location information while if $C_1 \geq C_2$, the forwarding is based more on the randomness. In any case, both the location information and the randomness are taken into consideration for the prioritization of the candidate list. Algorithm 3 illustrates this process.

V. PERFORMANCE EVALUATION AND SIMULATION RESULTS

To evaluate the performance of the different approaches, we pursued simulations using OMNET++ [21], followed by a discussion on the obtained results. For geographical forwarding we assume $C_1 = 1$. For delivery-based forwarding we assumed a high threshold equals to 80% and for geo-probabilistic we set $C_1 = 1$ and $C_2 = 1$ so the location and the random factor are equally weighted. The transmission range is 12m and the distance between the source and the destination is measured in hops. The number of the hops is decided through a simple traditional routing scheme, where each node forward the packet to the closest neighbor node.

A. Performance results

The different approaches are evaluated in terms of energy consumption, delivery ratio and average packet latency. Com-

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Algorithm 3: Geo-probabilistic forwarding.

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1 **if** *(isRTS(rts))* **then**
2   T_{RTS}= CalculateBackoff();
3   wait(T_{RTS}) + dblrand(0,1);
4   Channel=ChannelSensing();
5   **if** *(Channel==IDLE)* **then**
6   SendCTS(rts.SenderNode);
7   interval=T_{DATA};
8   reason=Listen(interval);
9   **if** *(reason==DATA)* **then**
10   SendACK(DATA.SenderNode);
11   **else**
12   GoToSleepMode();
13   **end**
14   **else**
15   GoToSleepMode();
16   **end**
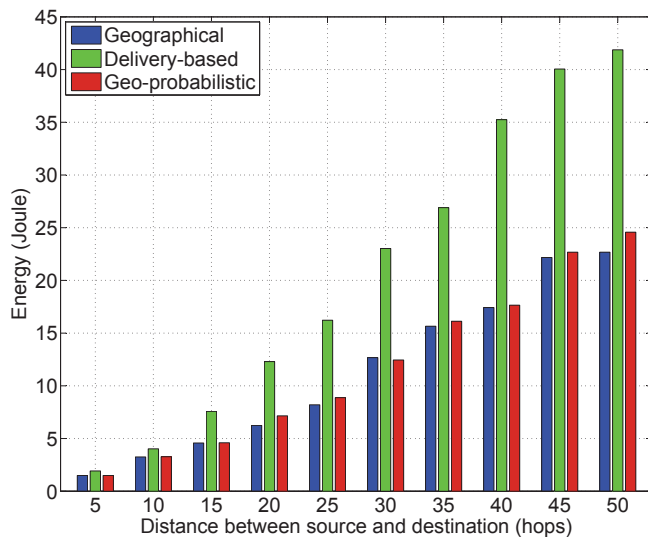17 **end**

Fig. 2: Energy Consumption.

Fig. 3: Packet delivery ratio.

munication parameters were chosen based on IEEE 802.15.4.

1) Energy consumption: Let the node power consumption in transmitting and receiving/idle modes be denoted by P_t and $P_{r/i}$ respectively. The sleeping mode power consumption is practically 1000 times smaller than P_t and $P_{r/i}$ which is negligible. Let $P_t = 15mW$ and $P_{r/i} = 10mW$, as in [22]. Figure 2 shows the simulation results.

When the distance between the source and the destination is small, all the approaches have similar performance. However, when the distance is increased, geographical and geo-probabilistic forwarding have better performance in terms of energy consumption. This is mainly because these two approaches try to find the node that is closer to the destination and forward the packet. Consequently, in every packet transmission, the best available path at the time of the transmission is followed. Hence, these approaches achieve minimum number of hops. The small difference between these two approaches can be explained by checking the selection criteria. Since geo-probabilistic forwarding has some randomness on the selection criteria, the source node has to remain active a bit longer than in geographical forwarding.

On the other hand, delivery-based forwarding has the worst performance over the other approaches. In this approach, the source node has to remain active for a long time in order to collect all the CTS packets. As a result, the energy consumption per packet is increased, and the total energy consumption is increased as well. Moreover, as the number of the nodes is increased, more nodes need to remain active while waiting for all the CTS packets. Thus, the total energy consumption is increased.

2) Delivery ratio: Delivery ratio can be used as a metric for the number of the successfully transmitted packets. Delivery ratio is crucial in monitoring applications where all the messages should arrive to the destination correctly and on time. Figure 3 shows the results.

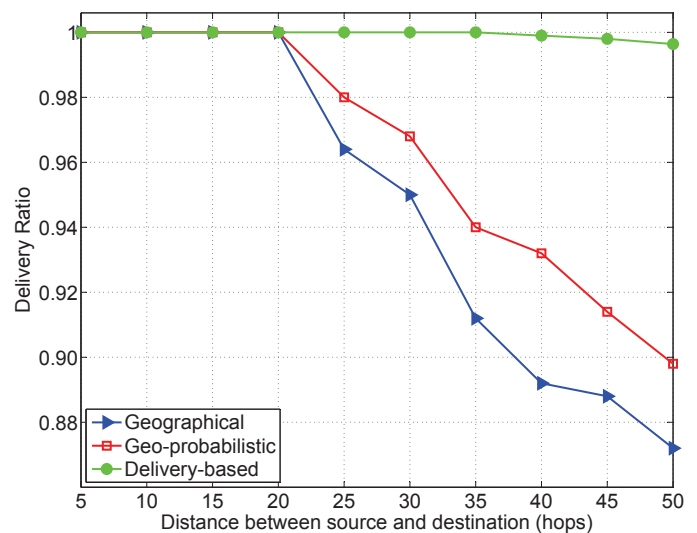In general, delivery ratio drops when the distance between the source and the destination is increased. This is primarily because of the traffic collisions and the packet loss caused by the high traffic volume. As the source to destination distance is increased, geographical forwarding and geo-probabilistic forwarding performs worse than the other approach. These two approaches tend to use the same node for message transmission leading to more collisions. As the number of the nodes that could participate in each transmission increases, more packets are lost and more collisions take place. Geo-probabilistic forwarding performs a little better because of the random criteria for the next relay node.

In contrast, delivery-based forwarding performs better than all the approaches. The use of the RSSI value as an indicator for the link reliability lead to a high delivery ratio. Only the most reliable links are selected and the packets are delivered to the destination without any packet loss. As a consequence, as the number of the candidate nodes is increased, this does not effect the routing principles of this approach.

3) Average packet latency: Packet latency is the number of hops that a message follows toward the destination. In our simulation, the source sent 1000 packets toward the destination. Figure 4 shows the results for the average message latency of the three opportunistic approaches.

Geographical and geo-probabilistic forwarding have similar performance. Since location information is included in the selection criteria of these two approaches, their performance is better than the other approach. They are trying to use the shortest available path in every packet transmission by using the nodes that are closer to the destination.

On the other hand, delivery-based forwarding has the worse performance over all the approaches. In this approach the most reliable link is followed. Although the packet will be transmitted with high PRR, the progress of forwarding the packet toward the destination will be small. This is because usually the most reliable link is toward the closest neighbor node. As a consequence the average packet latency is higher. Nodes tend to use the most reliable paths for packet transmissions. However, the average number of hops toward the destination
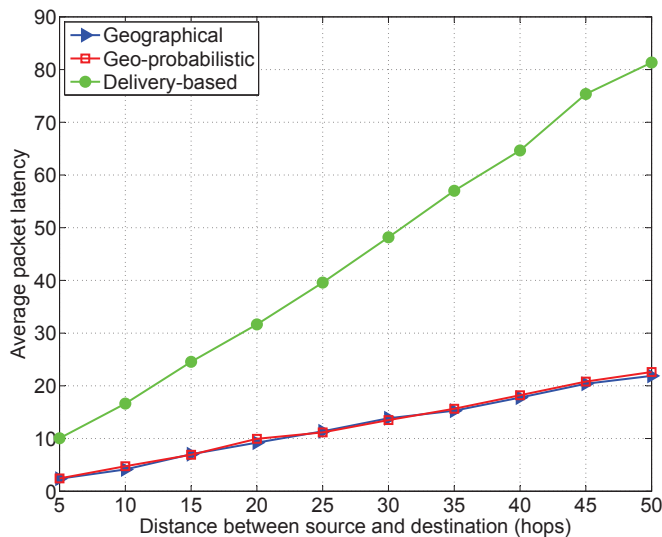
Fig. 4: Average packet latency for 1000 packets.

is increased and the packet latency is increased as well.

B. Discussion

As it can be inferred from the obtained results, the selection criteria have great impact on the network performance. The routing approach should carefully design the selection criteria following the QoS of the application. For instance, in a monitoring application, geographical and geo-probabilistic approaches can deliver better results in terms of packet latency. The packets will arrive at the destination on time, which is of crucial importance in such an application. Moreover, in a WSN where the replacement of the batteries of the nodes is impossible, the geographical and geo-probabilistic approaches can be used because of the low energy consumption. However, these two approaches will keep using the same nodes while they also require some location information which can not always be available.

On the other hand, in a complex indoor environment with high dynamic and lossy wireless links due to obstacles, distractions, etc., delivery-based approach might be followed. This approach is ideal since it can guarantee the delivery of all the packets to the destination with a small increase in the average packet time.

VI. CONCLUSIONS

In this paper we have examined the impact of the selection criteria on dynamic routing. A classification of the different approaches along with their routing algorithms was presented. The performance evaluation of the different approaches in terms of energy consumption, delivery ratio and packet latency was also examined. According to the achieved results, we concluded that the selection criteria have great impact on the network performance. In particular, different types of networks with different QoS requirements should use the appropriate selection criteria. Performance results of this work can be used as an indicator of the appropriateness of a dynamic protocol for different network applications.

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