A Survey on Agent Based Rumor Dissemination for Data Access in WSNs

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ABSTRACT: *In the context of Wireless Sensor Networks (WSNs) where positioning information is not assumed, we are interested in the way that rumors are disseminated using simple packets called agents and queries. Using rumor agents instead of messages may enhance data accessibility in terms of energy cost and bandwidth. Agent's cooperation helps to disseminate rumor about one or more events in the network with fewer transmissions and due to the lightweight of agent's packet size the limited bandwidth can be efficiently utilized. In this survey, we try to present, describe and compare the most recent rumor agent based dissemination protocols proposed in the literature for WSNs.*

Keywords: Wireless Sensor Networks, Bandwidth, Dissemination Protocols, Data Access

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1. Introduction

A Wireless Sensor Network (WSN) is a collection of sensor nodes (small sensing devices) and a sink node (base station) connected through wireless channels. These small devices can be used for building distributed systems for data collection and processing [1]. Generally, the sensor nodes detect events, performed desired measurements, process the measured data and transmit it to the sink node [2]. However, nodes may also generate queries to find events or locate data and services they are interested in within the network [3]. Sensor networks are suitable for data collection within regions that human beings are unable or hard to reach, for example, battle fields reconnaissance, disaster (such as earthquake, fire, etc), and areas monitoring. Other examples applications include health monitoring, intelligent building, etc [1].

Wireless Sensor Networks suffer from several restrictions, e.g., limited energy supply, limited computing power, and limited bandwidth. One of the main design goals of WSNs is to carry out data communication while trying to prolong the lifetime of the network. [4] Especially because of the energy constraint and the limited bandwidth, data dissemination in WSNs is challenging task. In fact, for routing purposes and for many other applications, maximum data has to disseminate over the WSNs. The design of routing and dissemination protocols in WSNs is influenced by many challenging factors; main of them have been summarized according to [4] as follows:

- **Node deployment:** node deployment in WSNs affects the performance of routing and dissemination protocol. The sensor nodes may be deployed in a deterministic manner with pre-determined paths to disseminate data or in a randomized way in an ad hoc manner with may be a non uniform distribution of sensor nodes to consider.

• **Energy consumption:** the most consuming action of a sensor node is information transmission. In a multi hop WSN, each node plays a role of a data sender, router and may be aggregator too. The failure of some sensor nodes due to the lack of power can cause significant topological changes and might require rerouting of packets and reorganization of the network. Thus, the design of routing and dissemination protocols in WSNs requires careful resource management.

• **Node Heterogeneity:** usually, sensor nodes are assumed to be homogeneous (have equal capacity of sensing, computing and transmitting). However, depending on type of applications, they may have different capacities. For example, in hierarchical protocols cluster heads nodes can be more powerful than other sensor nodes in terms of energy, bandwidth, and memory and are in this case exclusively devoted to routing, disseminating and data aggregating.

• **Fault Tolerance:** If some sensor nodes are broken or fails due to lack of power or physical damage, Meduim Access Control (MAC) and routing protocols must accommodate formation of new links and routes to the data collection base stations. One solution is to reroute packets towards regions where more energy is available or design routing protocols that ensure a tradeoff between the energy consumption and redundancy in the network.

• **Scalability:** WSNs are composed of thousands or hundreds of thousands of entities. So, routing and dissemination protocols should be able to scale to such high degree of networks.

• **Coverage:** In WSNs, each sensor node obtains a partial view of the environment, limited both in range and in accuracy. So, coverage is an important design parameter in WSNs.

To preserve energy consumption and the limited bandwidth of WSNs, many researchers have provided techniques using simple packets called agents and queries to spread data or a request of information all over the sensor network. With agent based dissemination techniques data can be accessed more efficiently. In fact, agent's collaboration may help to disseminate information about one or more events in the network with fewer transmissions. Also, agent's code consists of few lines of program. Thus, agent's transmission does not affect the limited bandwidth of WSNs. All agent based dissemination techniques presented in this survey are implemented in environments without any localization system. This is because, of the cost and the precision problems of using such positioning systems (to have a good precision we usually need more than three GPSs in an area without physical obstacles). The main problem with the agent based dissemination protocols presented in this survey is the spiral like routing paths and the non uniform distribution of agents in the network. The problem is the agents next hop choice in maintaining agent's trajectory as straight as possible preventing backwards paths. In this survey we present, describe and compare the most recent agent based techniques to disseminate data for routing applications in WSNs. The rest of this paper is organized as follows: section 2 defines a terminology background concerning agent's and query roles, creation and cooperation with other agents. A comprehensive survey of the most recent agent based data dissemination techniques is presented in section 3 and finally, section 4 concludes the paper.

2. Backgrounds

2.1 Model Environments

Once an ***Event*** occurred in the network, the sensor node that witnesses the event with sufficient precision creates an ***Agent***. An agent is a simple packet responsible for spreading rumors about detected events to distant nodes in the network. Each agent is associated with the Time To Live (TTL) that determines the number of hops the agent can traverse before it dies. An agent maintains an ***Event*** list in which the events names and the distance to the events in terms of hops are stored. Agents and nodes maintain their respective event lists. [5] We note that agents are considered as active messages with a small code of list synchronizations and are not like mobile agents used in WSNs for data collection or for a dynamic deployments of applications like cited in [6]. When the sink node is looking for a certain event, it creates a ***Query***. A query is a packet which only contains a call for specific information. It travels the network blindly and searches each visited node's event table for the information it needs until it discovers sooner or later a path to the event it is interested in. Each query is associated with a Time To Live (TTL) that determines the number of hops the query can make. A query is considered undelivered when it does not reach its destination before the expiration of its TTL. The neighboring information in the network is maintained by transmitting hello messages and

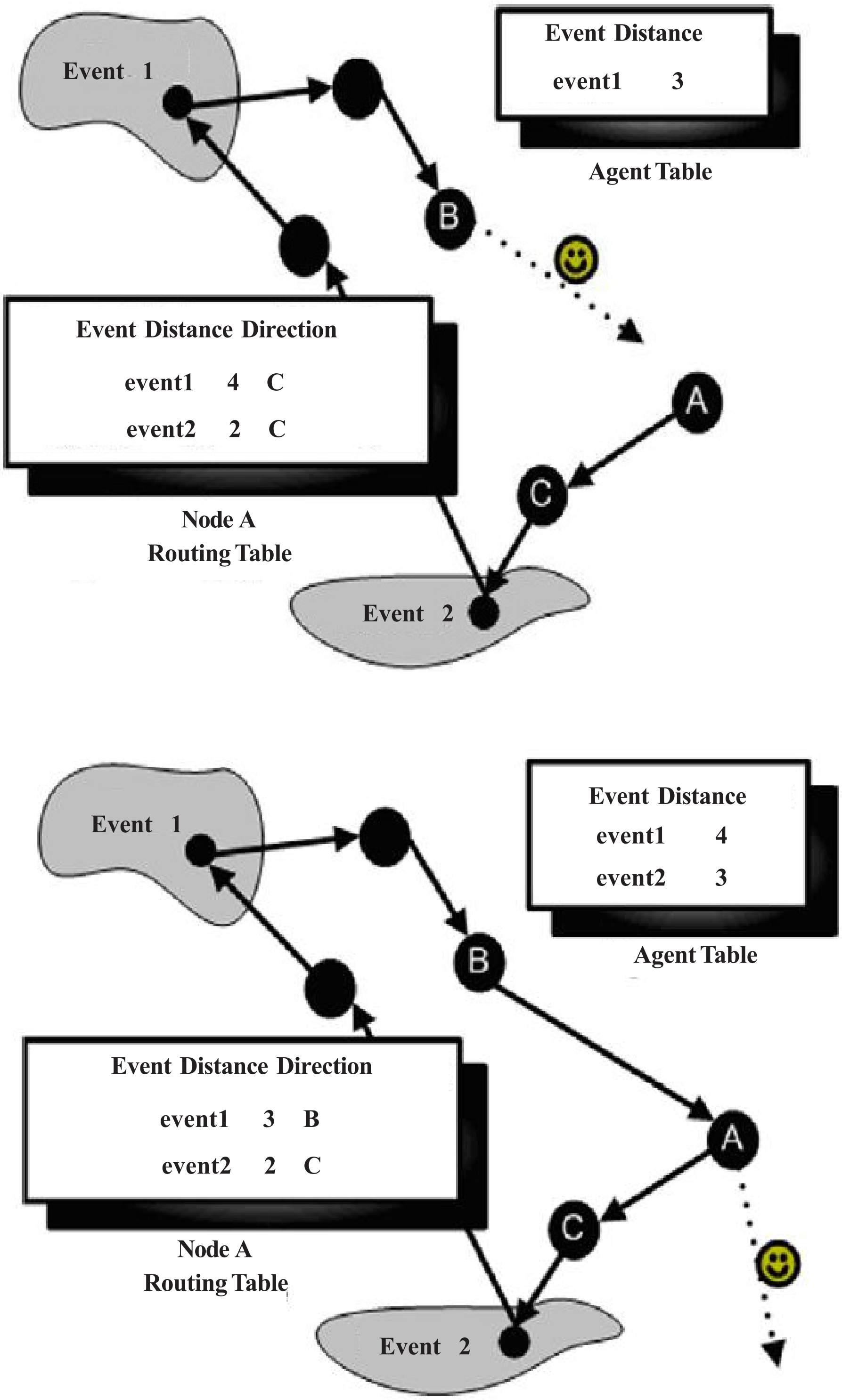


Figure 1. Synchronisation of agents and nodes lists [7]

neighbors ID are stored on ***neighbor list*** maintained by each node.

2.2 Agent's cooperation

Agent's cooperation is very important to maintain optimal paths to each event. The principal role of an agent is to inform nodes its encounters of any events it has witnessed along its route. To do so, the agent will precede to a synchronization of its event list and the routing table of the node it arrives on. Thus, like depicted in figure 1, when an agent arrives to node A from node B, it will update the route to event 1 that was previously towards node C with 4 hops to node B direction with only 3 hops. Also, since the agents witness a new event 2, it will precede to the double rumor propagation about both events 1 and 2.

3. Rumor agent based data dissemination protocols

Data dissemination in WSNs is strongly dependent on the type of applications and the environment interactions. It can be categorized as [7]: time-driven, event-driven, and query driven. In time-driven paradigm each sensor sends its own data in predefined intervals. In event-driven method, when a specified event occurred in the network, sensors which sense the event with a sufficient intensity, report the event to one (or several) predefined sink(s). In query-driven approach, every time a sink needs to collect data from current events or locate services, it sends queries in the network. This last paradigm is used in all the dissemination protocols presented in this section.

3.1 Rumor Routing

Rumor Routing (RR) [5] protocol attempts to solve the problem of the overhead and introduces a logical compromise between query and event flooding. In RR, when a node in the network witnesses an event, an agent is created and the event is inserted into an *EventList*. For its next hop, the agent chooses an unvisited node among its neighboring nodes. If all the neighboring nodes were already visited, the agent will choose one of them randomly. Once broadcasted, the agent and all the neighboring nodes that hear the broadcast synchronize their *EventList* which lead to the construction of a fairly thick path [8]. The agent will continue its traveling until the expiration of its TTL. For the historic, Agents also maintain the History list that contains the identity (IDs) of the previously visited nodes. When a query is sent by a sink node, it travels the network blindly until it crossroad an agent path of the event it is interested in. Only in the worst case, where the query cannot find a path to the event, it will be flooded. Figure 2, illustrates the crossroad of both agent and query paths so, the query is directly routed to the event source.

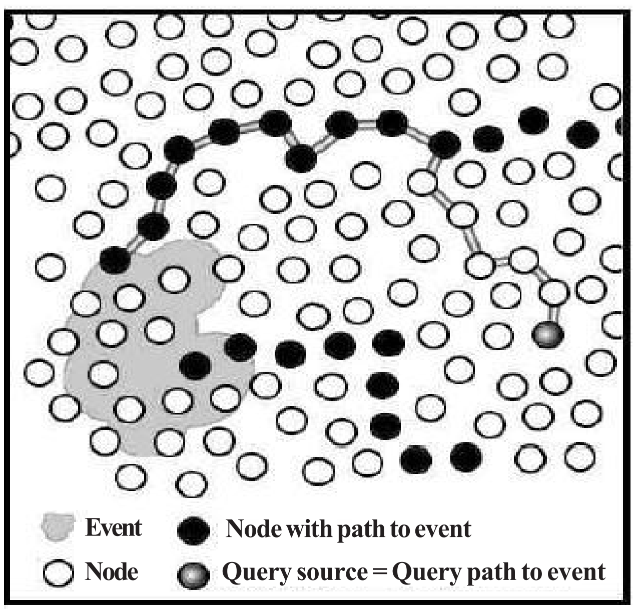


Figure 2. Path construction for data access in RR

Comparing to flooding mechanism, Rumor Routing can achieve significant savings on energy since the number of transmissions decreased without sacrificing delivery rate. It is a fault tolerant algorithm since multiple paths are created even if not necessarily optimal and the delivery rate decreased linearly with number of failed nodes. The drawback of RR is that it produces a highly non-uniform distribution of information due to the random choice of the next hop, when forwarding agents and queries. The agent path may be a spiral route around a restricted region in the network and the routes established between the sink and the source node are usually not the shortest one.

3.2 Zonal Rumor Routing

Zonal Rumor Routing (ZRR) [3] is an extension of the RR protocol. It was proposed to solve the problem of the non uniform distribution of information through the WSN. ZRR algorithm aims to increase the percentage of query delivery with fewer transmissions. ZRR also interests in cases where sensors are uniformly distributed in a sensor field, and provides a study around an optimal number of zones to maximize the query delivery rate. In ZRR, the topology of the network is reconsidered, since it is partitioned into virtual zones where each node is exactly member of one zone. Agents and queries are forwarded as far as possible in the network moving from a zone to another. For its next hop, the agent chooses a neighboring node belonging to a different zone as illustrated in figure 3. If this node does not exist, the agent is forwarded randomly as in RR.

ZRR seems to be a good approach to disperse agents and queries further in the network but there is no guaranty - even if they cross long distances - that both of them may loop back toward their native zones. This is because the historic information is temporary and the data structures may be overflowed. ZRR also consumes additional time and power during the zone creation phase.

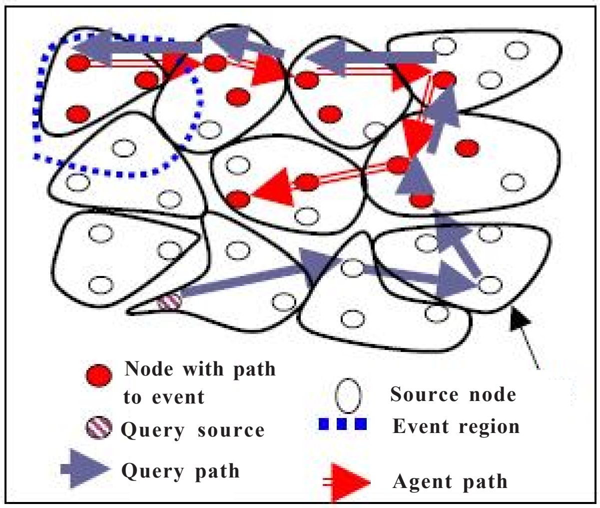


Figure 3. Agent and queries next hop in ZRR

3.3 Forking Agents

Forking Agents [9] was proposed to solve the same problem considered in ZRR and proposes to distribute agents more equally in the network. For that purpose, it introduces master agents that are sent immediately after detecting an event in a cell or a region of the network. The master agent packet's is composed of two packets: one for information and another for acknowledgment (ACK). The ACK packets guaranty a safe agent's transmission (there is no master agents lost in the network). Master agents have the property to fork themselves while traveling through the network for a predefined number of times. The forking process leads to child agent's creation. Child agents loose the property of forking and are transmitted unsafely (without ACK). The idea behind forking agents is to propagate the event information very far from the owner cell and in the same time reduce the number of transmissions (transmitting n agents from the source node that detects the event generates more traffic than transmitting one master agent that will fork in (n-1) child agents after a certain number of hops). Forking agents successes to ensure relatively a uniform distribution of events information in the network. However, no way is established to predict the directions of child agents since the system loose all control when creating them.

3.4 Along and Across Algorithm for Routing Events & Queries in WSN

Along and across routing algorithm [10] was developed for densely sensor networks with moderate traffic scenarios. It makes use of a hop tree structure organized on hop levels starting from a random root node. It consists of three major steps: building the hop tree, distribution of event attributes and propagation of queries. The initial step is based on broadcasting a Tree-build packet from the root node to all nodes in the network. The objective is that every node in the network knows its hop level according to the tree structure. In the second step, when events are detected in the network, they are distributed on neighbors along the same hop level. But all neighbors with different hop level that here the broadcast store the event in their event table. In the last step, queries are routed across hop levels to seek for a match. Queries may go on upper or lower directions or both to seek for an answer. If the query cannot be answered, then it will be flooded in the whole sensor network. Figure 4 shows an example of a constructed hop tree where the number in each node represents its hop level. An event is distributed along level 4 and a query initiated from level 2 node is propagated in the network looking for an answer. Simulation results show that the presented algorithm successes to consume up to 72.6% less transmission overhead. But, the broadcast transmissions especially those generated in the first step require precious battery power and paths between events and queries are usually not the shortest one.

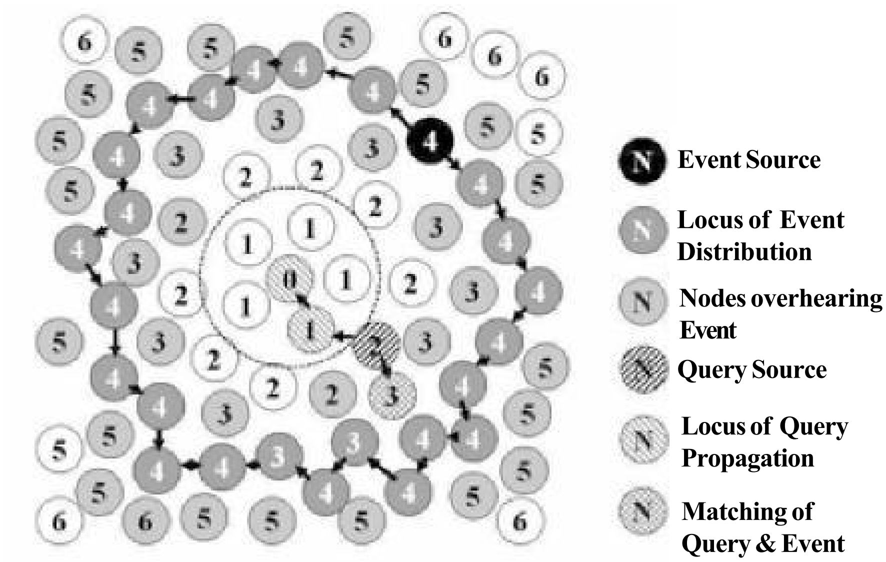


Figure 4. Hop tree structure in along and across routing algorithm

3.5 Straight Line Routing

Straight Line Routing (SLR) [11] focused first, on the problem of winding paths generated in the previous algorithms and proposed to transmit agents and queries on straight line trajectories. The winding path consists of more nodes than the straight path does. Consequently more transmissions will be generated. Secondly, SLR interested on eliminating the data structures used in Rumor Routing algorithm such as the History list that may grow in dense and large networks. So, the size of the routing packet is expected to grow also and consume more and more energy on agent and queries transmissions. To do so, SLR introduces new assumptions and supposes that when receiving a packet, each node has the ability of determining the identity (ID) of the sender node and the distance from the source node according to the signal strength. SLR algorithm steps consist on: 1. the construction of a candidate region, 2. the selection of the next hop. For the first step, each node has to maintain two variables: FlagIn (current node) and FlagOut (previous node). For each hop, all nodes that belong to the inside band of the current node (in a distance of R/2) enable their FlagIn and all nodes that belong to the outside band of the previous node (in a distance of R) enable their FlagOut. Nodes of candidate region are those that have both their FlagIn and FlagOut enabled. Fig. 5 illustrates the construction of the candidate region when an agent is in node A, coming from node B. For the second step, each node in the candidate region will activate a timer according to its distance from the current and previous node so that the nearest one from the straight trajectory will be chosen as next hop.

SLR algorithm was improved to face many situations and configurations of WSNs. For example, in networks with low density in which there is a high probability that no node is in the candidate region, SLR proposes adjusting the widths of Inside and Outside bands. SLR algorithm success to ensure fewer transmissions comparing to RR protocol since it minimize the deviation of both agents and queries paths. However, in case of network boundaries for example, how will the agent choose its next hop? In this case and since the agent has no path historic information, it may chooses backwards nodes.

3.6 Directed Rumor Routing

Directed Rumor Routing (DRR) [7] was proposed first for environments with available positioning systems. It focuses on improving the query delivery rate and the latency of the previous Rumor Routing algorithm using geographical routing. According to geographical positions, DRR proposes to disseminate agents and queries along a straitening trajectory to achieve

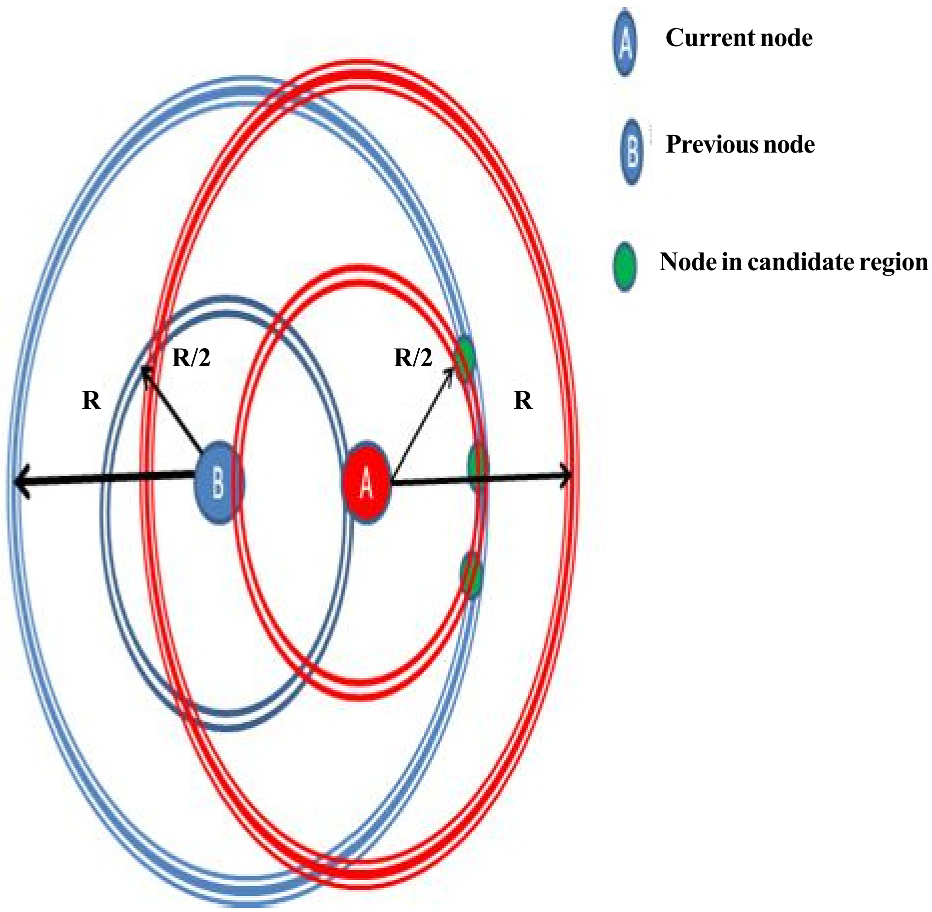


Figure 5. Candidate region construction in SLR

energy savings in terms of number of transmissions. Further, DRR was improved by eliminating the localization devices. In this case, cheaper and more available equipments like: Angle of Arrival (AoA) antennas, electronic compasses and signal strength detectors are used to obtain direction of the received signal, absolute directions and distances of different neighbors. Thus, each node can save the distance and direction of neighboring nodes in its routing table. For the next hop selection, agent (i) calculates for each neighbor, the summed value of: $D(i) = D(i-1) + d * \sin(a)$. Where ***d*** is the distance of the neighbor and ***a*** is the angle of the neighbor deviation. The neighbor with the least absolute total deviation is then selected as the next hop as seen in Figure 6. To prevent backwards path, and in case the agent encounters a face or a network edge, DRR selects the neighbor with the largest absolute total deviation as the next hop. DRR algorithm simulations show that compared to Rumor Routing protocol, optimal paths are constructed (in terms of hop count) even with removing localization devices. DRR is a fault tolerant algorithm since logical lists of neighbors are periodically updated in each node by receiving Hello messages. The drawback of DRR is the partial historic information of the visited nodes. The strategy of preventing loops is not clear, since its stores only the previous node that transmits the agent.

3.7 A Small-World Routing

A Small-World Routing protocol (SWRP) [12] proposed by Wu and al is a combination between flooding and Rumor Routing protocol. It was inspired from the small world theory that is used to model the relationship among people via strong and weak links. In a small world network, a query and an event node are considered as a persons and the path connecting the two nodes as a relationship between the two persons. In the first step of SWRP, when the agent searches for a path, it selects routes that are via some (α) nearby nodes (strong links) and other via some (β) nodes that are many hops away (weak links). Weak links are routes that contain a number of hops. For its subsequent steps, a recurrent propagation of strong and weak links is repeated. Figure 7 illustrates the propagation of both strong and weak links. A query is searching for a potential event from the left. In each occurrence of the search step, there are 2 strong links (depicted in solid lines) and 1 weak link (depicted in dotted lines). Each

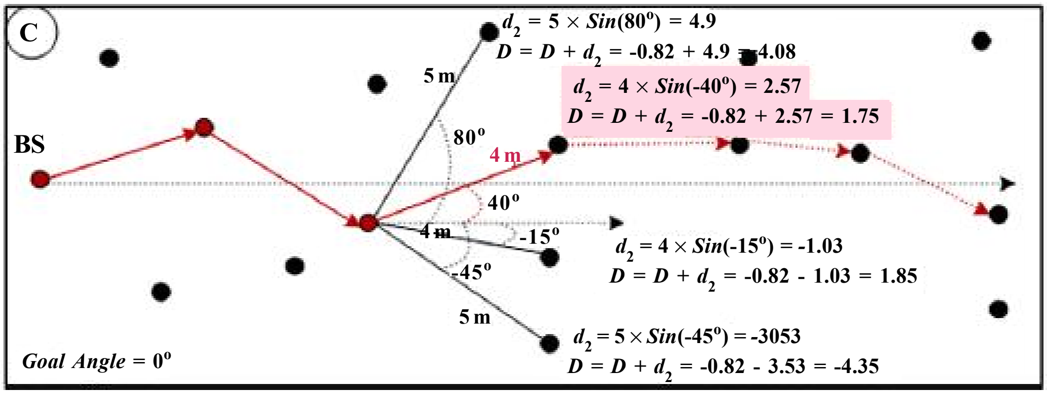


Figure 6. Next hop selection in DRR without GPS

weak links go in two hops. In a special case when $\alpha = 0$, the Small-World Routing Protocol is equivalent to the rumor routinrouting protocol with β being the number of agents.

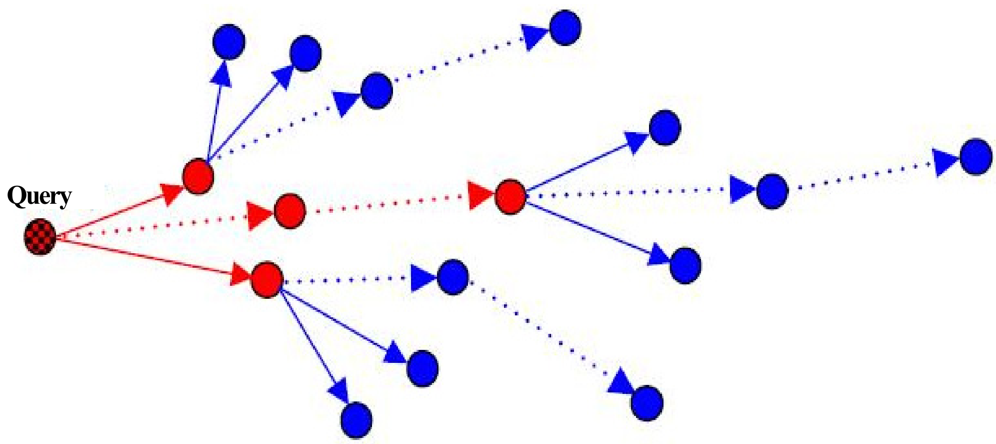


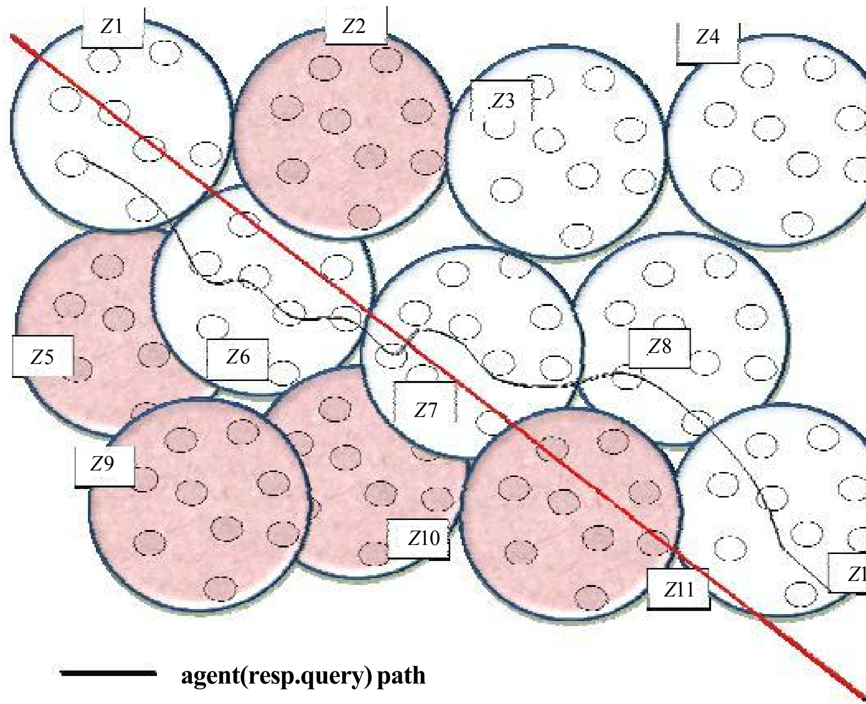
Figure 7. Strong and weak links construction in SWRP

Such tree expenditure in SWRP may generate too much broadcasts messages during the path discovering process. To solve this problem, SWRP proposes to limit the expansion of strong links and in some cases the weak links also. Performances results show that SWRP can find shorter paths with a higher successful rate when compared to Rumor Routing protocol. Also, the construction of multiple links offers more alternatives to find paths and makes SWRP a fault tolerant protocol. However, since SWRP perform diffusion and random walk propagation, the energy cost risk to be higher than in Rumor Routing protocol, so there is a need to measure it.

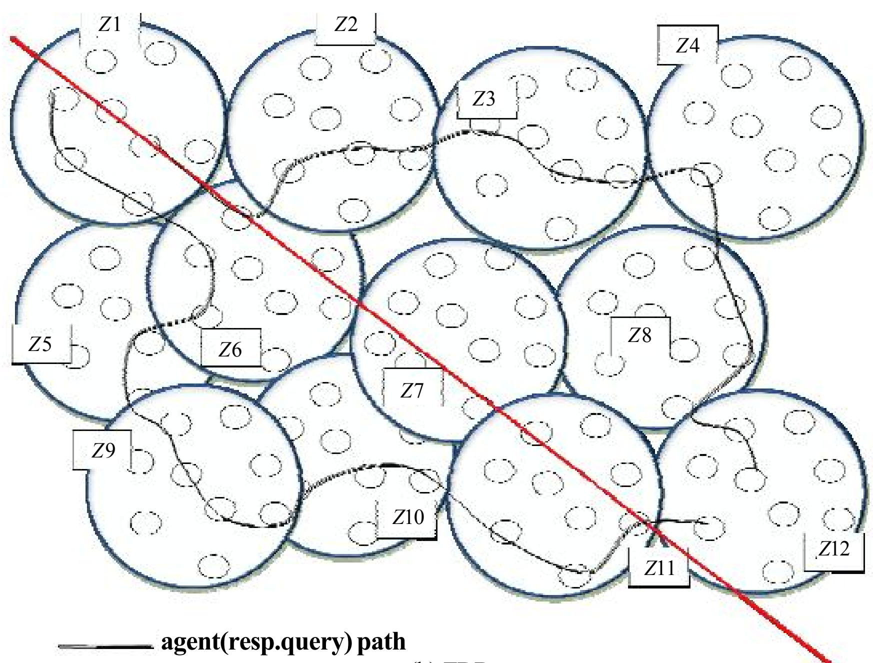
3.8 Fast Rumor Agents

Fast Rumor Agents (FRA) [13] is a direct extension of the previous Zonal Rumor Routing protocol; it considers the same network topology organized in virtual zones. FRA was designed to fix the spiral path routing problem and reduce response time. FRA offers to both agents and queries neighboring information at two hops in order to avoid visited zones. The neighboring information is embedded in lightweight packets frequently reinitialized. Thus, agents and queries may travel the network faster to far regions which reduce considerably the time of path establishment. Figure 8 illustrates the difference between FRA and ZRR approach for next hop selection. In (a) and at the beginning, the agent comes from zone 1 and is at the frontier of the zone 6. For its next hop, the agent will avoid nodes of zone 2 and 5 because they are neighbors to zone1. The agent will choose a node in the nearest zone (zone 7) as a next hop. For its entire next extra zone hops, the agent will avoid neighboring zones of its last visited zone to keep the trajectory as straight as possible. But in (b) the agent may be forwarded to nodes from zone 2 or zone

5 which makes the agent path longer and increases the probability of spiral paths. FRA protocol allows agents and queries to cross the network faster with loop free paths. Agents and queries dispose of two new characteristics which are the lightweight and the global historic view. Performances analyses show that FRA protocol achieves substantial improvements in terms of traffic and time of path establishment compared to the ZRR one. However, agent's path in FRA might take a larger circle around native region. In the other hand, the agent straight line trajectory will slightly decrease the query delivery rate since the rumor is disseminated along a thin path.



(a) FRA



(b) ZRR

Figure 8. Agent next hop selection

Metrics	RR	ZRR	FA	SLR	AL& AC	DRR	DRR without GPS	SWRP	FRA
Localization	No	No	No	No	No	Yes	No	No	No
Loop free paths	No	No	No	Yes	No	Yes	Yes	No	Yes
Neighboring inform. (hop)	1	1	1	1	1	1	1	1	2
Network architecture	/	Zone	/	/	Tree	/	/	/	Zone
Triangulation features	No	No	No	Yes	No	No	Yes	No	No
Fault tolerance	Yes	Yes	Yes	No ?	No	yes	yes	Yes	No
Shortest paths	No	no	no	No	yes	yes	yes	Yes	yes

Figure 9. Comparison of rumor agent based data dissemination protocols in WSNs

3.8.1 Synthesis

Depending upon network conditions and assumptions, each rumor agent based data dissemination protocol has its own advantages and disadvantages. Some protocol needs special network architecture before disseminating the rumor. In this case, an evaluation of the energy cost of this protocol creation phase has to be measured. On the other hand, other protocols exploit the partial or the complete neighboring information to predict the agent's trajectory in the network. Keeping such neighboring information may have an impact on network bandwidth and on overflowing data structures so; an optimal use of these data structures has to be ensured by these protocols. Instead, some other protocols use the triangulation metrics to ensure a straitening trajectory of both agents and queries. We summarize the agent based data dissemination protocols presented above in the Table shown in Figure 9. The table compares these protocols according to many metrics.

4. Conclusion

In this paper we were interested on a special data dissemination field, which consists on agent based rumor dissemination for data access in WSNs. We explained and described the most recent rumor agents dissemination techniques presented in the literature for WSNs. All the presented protocols have the common objective to disseminate agents and queries far in the network to ensure a uniform distribution of information in the network avoiding backwards paths. We highlight the use of agents instead of simple messages, as well as the advantages and drawbacks of each agent based dissemination technique. Also, we propose a comparison based on some criterion. Our aim is to provide a better understanding of the current research issues in this field and help designing new ideas to enhance the use of rumor agents in WSNs.

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