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A Survey on Data Dissemination in Wireless Sensor Networks

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Abstract Wireless sensor networks (WSNs) have been applied in a variety of application areas. Most WSN systems, once deployed, are intended to operate unattended for a long period. During the lifetime, it is necessary to fix bugs, reconfigure system parameters, and upgrade the software in order to achieve reliable system performance. However, manually collecting all nodes back and reconfiguring through serial connections with computer is infeasible since it is labor-intensive and inconvenient due to the harsh deploying environments. Hence, data dissemination over multi-hop is desired to facilitate such tasks. This survey discusses the requirements and challenges of data dissemination in WSNs, reviews existing work, introduces some relevant techniques, presents the metrics of the performance and comparisons of the state-of-the-art work, and finally suggests the possible future directions in data dissemination studies. This survey elaborates and compares existing approaches of two categories: structure-less schemes and structure-based schemes, classified by whether or not the network structure information is used during the disseminating process. In existing literatures, different categories have definite boundary and limited analysis on the trade-off between different categories. Besides, there is no survey that discusses the emerging techniques such as Constructive Interference (CI) while these techniques have the chance to change the framework of data dissemination. In a word, even though many efforts have been made, data dissemination in WSNs still needs some more work to embrace the new techniques and improve the efficiency and practicability further.

Keywords wireless sensor network, data dissemination

1 Introduction

Wireless sensor networks (WSNs)[1-2] have been attracting extensive attention from both the scientific community and industry. The technological advances have enabled the development of low cost, low power, multi-functional sensor devices, boosting the extensive deployment of real application systems. Many real deployed systems have been applied in a variety of application areas such as structural health protection[3-4], environment monitoring[5-6], coal mine monitoring[7], event detection in targeted monitoring areas[8], and habitat monitoring[9].

As a promising network prototype, WSNs have attracted the interest of many researchers from many aspects. Localization[10] is a fundamental area since many applications such as navigation[11] and location-based services need it as a basic component. Time synchronization[12] is another fundamental service for many other applications. Diagnosis[13] is a hot topic for network management. Routing strategy[14] is well studied for data collection applications. Operating system[15] and programming framework[16] are studied for improving efficiency of software. The capacity of WSNs[17] and energy control[18] are being researched for better utility and efficiency. With the growing number of WSN application systems, measurements of these deployed systems[19-21] are presented for instructions for further deployments. Besides the above mentioned topics, there is another crucial area in WSNs — data dissemination, which is the inverse of data collection.

Most of WSN systems, once deployed, are intended to perform unattended operation for quite a long period. During their lifetimes, it is necessary and unavoidable to fix software bugs, reconfigure system parameters, and upgrade the software in order to achieve reliable system performance. Unfortunately, for a large WSN system, manually collecting and reconfiguring nodes is infeasible since some WSN systems are deployed in areas where it is physically impossible for hu-

Survey
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man beings to access. It is also labor intensive due to the huge number of nodes. As an alternative, disseminating data over a multi-hop network is a promising technique.

As a core building block, data dissemination has attracted many researchers in recent years. In this survey, we discuss the challenges in data dissemination and the design requirements of data dissemination schemes. We review the existing methods by dividing them into two categories: structure-less schemes and structure-based schemes. Generally, all data dissemination schemes can be classified into these two categories according to different assumptions about the knowledge of network structure information. In structure-based schemes, knowledge of network structure information such as location and topology is assumed. Dissemination therefore may take advantage of this knowledge to construct a dedicated structure for efficient dissemination. In structure-less schemes, there is no network structure information and no dedicated structure for dissemination.

For structure-less schemes, we further divide them into non-negotiation schemes and negotiation-based schemes according to whether or not a negotiation mechanism is used. Negotiation mechanism is intended to control the redundant transmissions and to guarantee the reliability requirement. However, negotiation is a double-edged sword. It brings about additional communication overhead and time consumption. In non-negotiation schemes, without a control message, the dissemination process is relatively quick but it is hard to provide arbitrarily high reliability. Besides, if not properly controlled, non-negotiation schemes may bring about the broadcast storm problem.

In structure-based schemes, there are two subcategories: plain-structure and hierarchy-structure schemes. In plain-based schemes, all nodes have equivalent status in the disseminating process. The structure information is only used for reducing the redundancy and does not affect the forwarding strategy. While in hierarchy-structure schemes, the information is used to construct a dedicated disseminating structure. Nodes are divided into clusters with a cluster head for each. The cluster heads therefore form a backbone network to get data preferentially and then disseminate data to the cluster members in their own clusters.

The merits and demerits of corresponding schemes are emphasized in this survey. In the existing literature, however, different categories have definite boundaries and no trade-off has been analyzed before. In this survey, we will analyze the trade-offs between different categories. The hybrid schemes, combining non-negotiation and negotiation-based schemes, are discussed and analyzed. Further, new techniques such as Constructive Interference (CI) can probably change the current working framework of data dissemination. In conclusion, even though much effort has been made, data dissemination in WSNs still needs a lot of work to realize practical applications for deployed systems.

The rest of this paper is organized as follows. In Section 2, we present the requirements and the challenges of data dissemination. Then we review the structure-less data dissemination scheme in Section 3 and the structure-based data dissemination scheme in Section 4. Section 5 introduces some related techniques that can be employed in data dissemination. Then we summarize the metrics of performance and present the performance comparisons of existing data dissemination schemes in Section 6. We discuss future directions in Section 7 and finally give the conclusion in Section 8.

2 Requirements and Challenges

In this section, the features of WSNs are presented firstly in Subsection 2.1. Then we state the data dissemination requirements in Subsection 2.2. Owing to the intrinsic features, in Subsection 2.3, we summarize the corresponding challenges in meeting the requirements.

2.1 Features of WSNs

In WSN systems, it is common to deploy many sensor nodes in targeted areas which may be physically inaccessible for human beings. For example, for volcano monitoring[22], the environment is unstable, making it impossible for system administrators to maintain the network on site. For the sake of the application requirements, compared with traditional wireless communication systems, WSNs have the following outstanding features.

- *Large Scale.* Depending on the deployment area, the amount of sensor nodes may be very large since the communicating range may be only dozens of meters.
- *Long Term.* Generally speaking, once deployed, the system is intended to work for a long time. A too short life time results in weak applicability.
- *Limited Resources.* Sensor nodes are powered by battery. Hence, the energy is limited. Besides that, data storage and computational capacity are also limited.
- *Low Power.* Because of the limited energy and long term life time requirements, sensor nodes work in a so-called duty-cycle mode. A node wakes up periodically to do certain tasks and then sleeps for most of the time. In the sleeping mode, the power consumed is reduced to the minimum.
- *Dynamic Network.* WSNs are ad hoc networks which maintain the topology by themselves. As a re-

sult, environmental changes affect the network significantly. Hence, WSNs are dynamic all the time.

2.2 Requirements of Data Dissemination

Data dissemination spreads data from sink node(s) to all nodes in the network, through wireless communication. Data can be a code image of a renewed program, system commands, or updated system parameters. Generally speaking, to satisfy the quality of services (QoS), there are three requirements of data dissemination in WSNs.

Reliability. Data dissemination usually requires a near 100% reliability. Here 100% reliability has two meanings: 1) all the nodes in the network are covered; 2) every node receives the entire data block as a whole without any hiatus. Since data dissemination is the building block of many services such as reprogramming and parameter distribution, any mismatch of the above two aspects may result in inconsistency or crash of network. Hence, 100% reliability is the most important requirement as the essential goal of data dissemination.

Efficiency. Specially, time-efficiency and energy-efficiency are the two most important efficiency requirements. Time-efficiency means the dissemination process should be finished as soon as possible, because during the dissemination process, a large number of data dissemination packets occupy the channel for long time, which hinders the collecting traffic. The systems will be blocked and inefficacious during this period. Therefore, this time period is required to be as short as possible.

Energy-efficiency desires the process to be done with minimal energy consumed. This is the consequence of limited power resources, which is a particular feature of WSNs. The consumed energy consists of read-write of flash, transmission of radio, and idle listening of radio. The read-write of flash is inevitable for storing data blocks. Radio activity is the major part of energy consumption and also the part that can be controlled. Hence, the radio-on time in data dissemination needs to be restricted.

Scalability. A satisfactory data dissemination scheme should adjust to any scale, in terms of the number of nodes and the node density. The dissemination protocol can be regarded as scalable if the completion time of dissemination is linearly increasing with network scale.

2.3 Challenges of Data Dissemination

As a result of the distinctive features of WSNs and the characteristic requirements, data dissemination in WSNs faces several challenges.

High reliability is usually desired by dissemination but is not trivial to obtain. Dynamic networks make the connectivity of network change all the time. Some nodes may break away from their networks and return some time later. Data dissemination should cope with this situation and guarantee that these nodes also have the ability to catch up and get the data.

Too many redundant transmissions result in the so-called broadcast storm problem[23]. The extremely heavy traffic raises the risk of interference with collisions of packets. To make data dissemination reliable and efficient, the broadcast storm problem should be avoided.

The larger the data are, the more energy is consumed. To be energy-efficient, dissemination should try to minimize the radio-on time. Hence, except for the obligatory transmission cost, the extra use of the radio should be cut to the minimum. However, some schemes such as negotiation-based schemes need to turn on the radio for overhearing and conducting the negotiation.

Limited resources bring limitations to the dissemination. Mica[24], released in 2001, has 4 KB RAM and 128 KB flash; Telos[25], released in 2004, has 10 KB RAM and 48 KB flash. Dissemination should fit the capacity of node platforms, for example, if the size of data is larger than the size of RAM, it is impossible to transmit the whole data block at one time.

General routing protocols are designed for data collection. They are unsuited for data dissemination since data collection is usually a many-to-one communication model while dissemination is a one-to-many communication model. More specifically, in data collection, all nodes in the network send data to the sink which forms bottom-up data flows; while in data dissemination, all nodes receive new data from the sink which forms top-down data flows. Hence, general routing protocols fail to disseminate data efficiently. Many protocols tailored to data dissemination are proposed, as introduced in the following sections.

3 Structure-Less Data Dissemination Schemes

In structure-less data dissemination schemes, there is no dedicated structure constructed for dissemination. Generally, schemes in this category do not relay on underlying network topology. Without topology information, local optimal strategy is adopted to greedily approximate global optimal solution. The disadvantage of these schemes lies in their inability to achieve a global optimal solution. The advantage is that no additional overhead is needed to acquire global topology information and construct a dedicated structure. Compared with structure-based schemes, structure-less schemes are preferable in dynamic networks.

Structure-less schemes can be further divided into two categories, non-negotiation schemes and negotiation-based schemes, based on whether a negotiation strategy is employed in a particular scheme.

3.1 Non-Negotiation Schemes

Classic flooding is a straightforward approach without negotiation. In classic flooding, the dissemination is started by a sink node. The sink sends out data to all of its neighbors. Upon receiving a piece of data, each node stores the data and checks whether it has already forwarded the data to its neighbors. If not, it forwards a copy of the data to its neighbors by broadcast, otherwise, it remains silent. Classic flooding maintains very simple control logic and disseminates data quickly in a network where the bandwidth is not scarce and the link quality is good enough. It is therefore simple yet effective.

The deficiencies of classic flooding make it inadequate to solely adopt classic flooding as the dissemination protocol for WSNs. Firstly, classic flooding is unreliable. In this approach, there is no automatic repeat-request (ARQ) scheme adopted and hence no reliability guarantees. ARQ is an error-control method for data transmission that uses acknowledgements (messages sent by the receiver indicating that it has correctly received a data frame or packet) and timeouts (specified periods of time allowed to elapse before an acknowledgment is to be received) to achieve reliable data transmission over an unreliable service①. It is obvious that the fraction of receiving data is decreasing exponentially with the increase in the hop count. However, high reliability is a desired characteristic and a basic requirement. As a result, classic flooding has to repeatedly broadcast data to provide a high reliability, resulting in less efficiency.

Secondly, classic flooding has the risk of incurring the so-called broadcast storm problem [23]. In classic flooding, nodes always send data to neighbors, regardless of whether or not the neighbor has already received all data. Since wireless communication is broadcasting and a node may hear several senders in its transmission ranges, many rebroadcasts are therefore redundant and collide easily. Besides, if ARQ is employed for the reliability, the collision will be more serious since all receivers send the ACK back immediately after receiving the packets. Therefore, if not properly used, classic flooding will result in serious redundancy, contention and collision, which researchers refer to the broadcast storm problem. [23] discusses how serious the storm is through analyses. It shows that the broadcast storm problem is aggravated by high density and large scale.

Based on the above observations, the authors of [23] proposed five revised flooding schemes: probabilistic, counter-based, distance-based, location-based, and cluster-based. Among these schemes, probabilistic and counter-based schemes are two light-weight schemes that modify classic flooding slightly; distance-based and location-based schemes assume the knowledge of geography information; the cluster-based scheme is a structure-based scheme, which will be introduced in the following section.

All these schemes are designed to alleviate the broadcast storm problem from two directions: 1) reducing the possibility of redundant rebroadcasts; 2) differentiating the timing of rebroadcasts.

Probabilistic scheme is to reduce the possibility of redundant rebroadcasts by reducing rebroadcasts intuitively. On receiving a fraction of data for the first time, a node will rebroadcast it with the probability P. Clearly, when $P = 1$, this scheme is equivalent to classic flooding.

Counter-based scheme is a density-aware method. When a node is waiting to transmit a packet, if more than C identical packets are overheard during this period, it will drop the transmission of this packet. Notice that all these schemes differentiate the timing of rebroadcasts by inserting a random back-off delay before the rebroadcast.

Since all the parameters (e.g., P and C) are preset based on experience, they may be deficient when encountering dynamic networks. For this reason, the authors of [26] proposed the revised versions which can adaptively change the parameters. Instead of using the constant parameters of previous work, the proposed schemes allow nodes to choose parameters based on local information. For example, in Fig.1, the rebroadcasting probabilities of B and C should be different due to the different local network features. Intuitively, C should rebroadcast with smaller probability, compared with B, since the density is high in C's local network and its rebroadcast may bring less benefit and more harm instead.

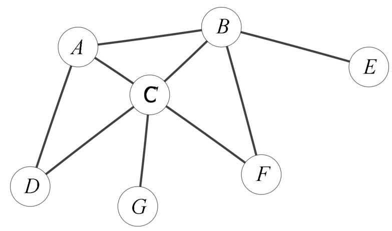

Fig.1. Exemplified network topology.

Gossip[27] is an alternative to the classic flooding approach that uses randomization to alleviate the storm problem. Actually, it is similar to the probabilistic scheme[23]. Haas *et al.*[27] studied this scheme in de-

① http://en.wikipedia.org/wiki/Automatic_repeat_request, Apr. 2014.

tail. They proposed the adaptive gossip protocol which allows a node to choose its gossip probability in inverse proportion to the number of neighbors it has. We designate this scheme as the Adaptive Neighbor approach. This scheme only considers the routing efficiency by assigning the probabilities adaptively. However, it has the risk of making the wrong decisions. Take the network in Fig.1 as an example. Node A is the sink node that initiates the dissemination. Clearly, to reliably disseminate data to the whole network, node C must rebroadcast every packet to its child G. However, based on the strategy of Adaptive Neighbor, we find that node C will choose a small rebroadcasting probability because of its large number of neighbors.

Trickle, was proposed in [28] as a method that manages how codes update. Trickle adopts periodical broadcasting data summaries to maintain consistency in local areas. It adopts an exponential back-off timer to improve unnecessary summary exchanges. If a local network is consistent, the time period of broadcasting a data summary is long. Otherwise, the period is quite short to disseminate data efficiently. Trickle further reduces unnecessary summaries by a "polite" policy which enforces a node dropping broadcast when an identical data summary is heard. Besides, the adaptive scheme is also used in this work. The rebroadcast probability of a message is adjusted based on the overhearing number of the last message. Consider the topology in Fig.1, again the deficiency is found. Node C will drop many broadcasts since it will overhear duplicate summaries from nodes A, B and D.

Smart Gossip[29] fixes the above problem by tuning the rebroadcast probabilities according to the underlying network topology. Note that the reason for an improper decision made by C in the above two schemes is that a node chooses its rebroadcasting probability independent of how many other nodes depend on it. Here node X "depends on" Y means that Y gets data from X. The stronger the dependency is, the smaller probability that Y can get data from other nodes except X. In Fig.1, G depends on C totally and E depends on B totally. Hence, in Smart Gossip, C will learn the knowledge that G depends on it totally. After getting this knowledge, it will increase the rebroadcasting probability until 1. Despite of making adjustments based on topology information, Smart Gossip is a structure-less method since it only uses local topology which can be obtained in a decentralized manner.

3.2 Negotiation-Based Schemes

A negotiation strategy was designed to overcome the broadcast storm problem and to obtain high reliability. Negotiation was firstly proposed in SPIN[30-31]. Before transmitting data, nodes in local areas negotiate with each other about who should be the forwarder and what is to be transmitted. Negotiation helps ensure that only useful information will be transferred and only one node sends out the data in a local area. Transmissions of redundant data messages are dramatically reduced. Generally speaking, negotiation uses three types of messages to consult the transmissions through a three-handshake.

- ADV (new data advertisement): this message specifies the data that a sender wants to share in the form of meta-data.
- REQ (request for data): nodes send back requests after receiving the ADV to specify which packets are wanted.
- DATA (requested data packets): the source node packs the requested packets and broadcasts the packed packets.

Sensor Protocols for information via negotiation (SPIN) is a family of adaptive data dissemination protocols that leverage the so-called negotiation strategy. The SPIN family of protocols rests upon two basic ideas. First, to achieve energy efficiency and avoid redundant transmissions, nodes need to share the information about which parts of the data they already have and which parts are still needed. However, sharing this information can be costly. Exchanging real data may be an expensive network operation since the data are usually of a large size. However, exchanging the summaries about disseminating data needs not to be. Meta-data is a common approach that is used to succinctly and completely describe the latest data. Meta-data keeps the identifiability of the original large data. That means the meta-data of the distinguishable data will still be distinguishable. The indistinguishable data will result in identical meta-data. Second, to prolong the lifetime of the system, an energy balancing strategy is adopted in SPIN. The nodes monitor their own energy resources and change the dissemination behaviors correspondingly.

As a pioneer of negotiation-based schemes, SPIN designs the negotiation strategy which is followed by later work. SPIN starts with the broadcasting of the ADV messages to announce which data the sender has. When receiving an ADV, the receiver will check its own meta-data with the one in the ADV message. If the meta-data are not matched and the sender has a newer version, the receiver will respond by sending an REQ message that specifies the wanted parts of the data. After receiving REQ messages, the source node sends out DATA messages which contain all the requested data.

Fig.2 shows an example of the procedure of negotiation in SPIN. Node A initiates the dissemination by broadcasting an ADV message to announce its possession of new data (Fig.2(a)). Upon receiving the ADV from A, nodes B, C and D respond by sending an REQ back if they want the new data or have missing data (Fig.2(b)). When A receives the REQ packets, it combines the REQ messages and packages the DATA messages that contain all the requested data (Fig.2(c)). Notice that if a link is unreliable, the DATA packets may be lost. The procedures in Figs. 2(b) and 2(c) repeat until all the required DATA packets are received or the maximum number of retries is reached. If a receiver does not get the whole data after the maximum number of requests, it stops sending REQ and waits for the next ADV message to start a new round. The receivers that get all the requested packets will broadcast ADV messages to serve as forwarders (Fig.2(d)). Then the neighbors who need the data send REQ messages back to C, after hearing its ADV (Fig.2(e)). Finally, by the way same to the one in Figs. 2(b) and 2(c), C broadcasts the data to all the neighbors (Fig.2(f)).

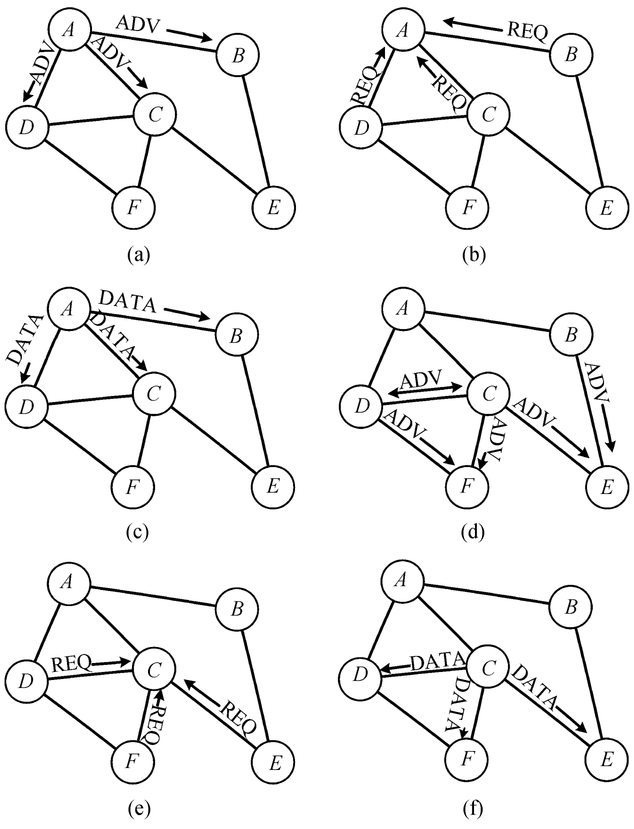

Fig.2. Negotiation process in SPIN.

Different from SPIN, Multihop Over-the-Air Programming (MOAP)[32] notices the forwarder contention problem. All the receivers that have new data can sever as forwarders, resulting in the competition about which node should be the forwarder. To solve this problem, MOAP selects only a small subset of the nodes in a neighborhood to act as forwarders, reducing the traffic. The repair mechanism is a simple sliding window based retransmitting method. Retransmissions are done through unicast to reduce the traffic further.

Deluge[33] is a popular reliable data dissemination protocol, which is built on Trickle but adds the support for the dissemination of large data by exploiting a three-handshake negotiation strategy similar to SPIN. Deluge exploits NACK to guarantee the reliability. It requires the requesters specify the wanted packets in the REQ messages. Then the missing packets can be selectively retransmitted. Different from MOAP, Deluge leverages the segmentation and pipelining mechanism, which will be introduced in Subsection 5.1. By this mechanism, Deluge can exploit the spatial multiplexing to speed up the dissemination process. Besides, the error recovery is done in a single hop to guarantee the reliability hop by hop.

The state diagram of Deluge is shown in Fig.3. All the nodes are in *maintain* state and periodically send out ADV messages to announce their data versions. When an ADV message with newer version is received, a node changes into *RX* state and sends the REQ messages back. If all the requested packets are received or the maximum number of retires is reached, the node turns to the *maintain* state again. Upon receiving an REQ message, the sender changes into *TX* state and transmits the requested data packets.

MNP[34] uses the same negotiation framework as Deluge. MNP shares many common ideas with Deluge. The key difference is that MNP designs a sender selection mechanism to overcome the deficiency of Deluge. Recall that in Deluge, if there is more than one candidate sender in a local area, neighbors randomly pick out a candidate as the desired source. By this method, the number of forwarders will not be bounded and can still be large to have the forwarder contention problem. This method also shows its deficiency when the source node has poor link qualities to its neighbors. MNP tries to solve this problem by the greedy sender selection algorithm, which greedily selects the candidate sender that has the largest expected *impact*. *Impact* here is defined as the expected number of neighbors that can get data from a node if they select it as the forwarder.

The state diagram of MNP is shown in Fig.4. All the nodes are in *maintain* when there is no data dissemination. The nodes periodically send out ADV messages. If an ADV message with new data announcement is received, the receiver changes to *idle* state and sends out REQ messages. The node that receives REQ does not change to *TX* state directly as Deluge does. It changes to the *sender selection* state and listens to the channel for a certain period. If an REQ withlarger *reqCnt* is heard but the REQ is not intended for it, the node will

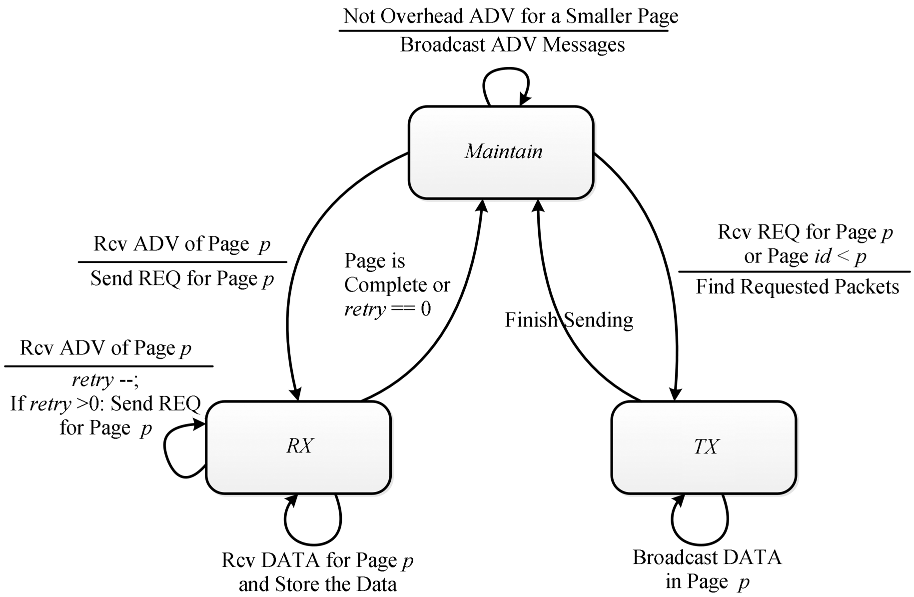

Fig.3. State diagram of Deluge.

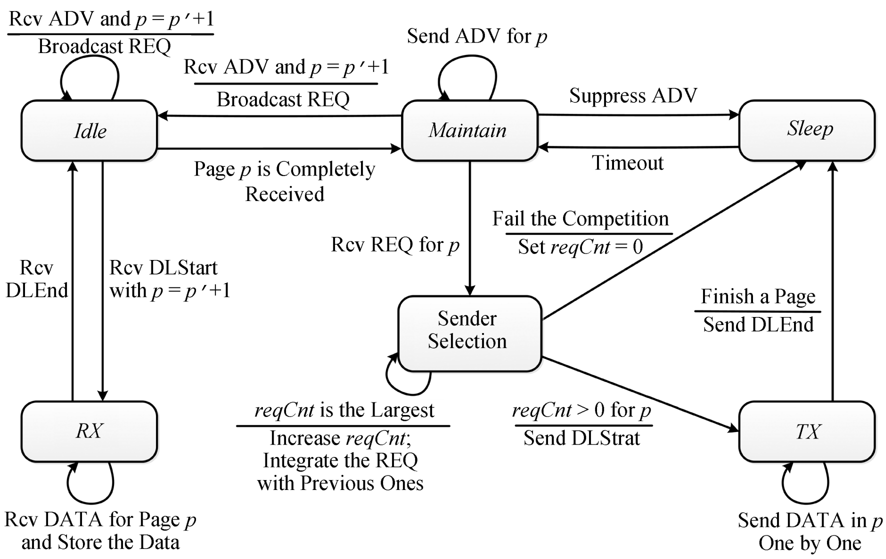

Fig.4. State diagram of MNP.

will quit the sender selection by resetting the *reqCnt* counter. It also goes to *sleep* state for energy saving. If it is the one receives the most REQ messages, it changes to *TX* and broadcasts a DLStrat message to announce the start of the data transmissions. Upon receiving a DLStrat message, the receivers in *idle* change to *RX* state and wait for the requested data. After downloading, the sender broadcasts DLEnd for stopping the downloading and goes back to the *maintain* state. Receivers also go to the *maintain* state.

ECD[35] is an efficient code dissemination protocol leveraging 1-hop link quality information to accurately measure the *impact* of a sender. MNP designs *impact* as the sender selection metric. However, the *impact* measurement of one node only considers the number of neighbors that need data from it without considering the link qualities. Hence, MNP can perform well in the networks where the links are reliable or near reliable but fail to work well when the links are lossy. Different from MNP, ECD takes the link quality into the consideration and calculates the *impact* as follows.

$$Impact(i) = \sum\nolimits_{k \in N(i)} 1 \times p(i,k), \qquad (1)$$

where $N(i)$ is the set of the uncovered neighbors of node i, $p(i,k)$ is the link quality from i to k. (1) reflects the expected number of packets received by the uncovered neighbors if node i is selected as the forwarder.

ReMo[36] is a reliable reprogramming protocol tailored to the mobile sensor networks. In the mobile sensor networks, the location of a sensor node is uncertain and the network environment is changing all the time. This intrinsic feature brings challenges to the protocol design. First, the uncertain locations make nodes have no information about neighbors. Second, the sender selection algorithm in ECD does not work since the PRR measurement is impossible due to the continuous variations caused by the nodes' mobility. ReMo was proposed to perform reliable data dissemination by overcoming the challenges. Nodes with ReMo learn the neighbors' information such as link qualities and relative distances by measuring the link quality indicator (LQI) and received signal strength indicator (RSSI) of the received packets. Based on the measurement results, the nodes in local area select the best node for data exchanging. ReMo also adopts the polite gossip advertisements as Trickle does. The advertisement rate is adjusted according to the network density. Another distinguishable feature of ReMo is that it allows disordering reception of data since the mobility of nodes makes hop-by-hop reliability guarantee hard.

4 Structure-Based Data Dissemination Schemes

Contrary to the structure-less schemes, structure-based schemes take advantages of the network topology and node location information to gear up the dissemination. Recall that in the structure-less schemes, some approaches also use the local neighbor information. However, it is not necessary. Without the prior topology information, the structure-less schemes can also work and learn the local information through the disseminating process. On the other hand, structure-based schemes need a prior knowledge of the topology information, which is usually the global topology.

In structure-based schemes, there are two subcategories: plain and hierarchy. In the plain-based schemes, all nodes have equivalent status in disseminating process. The network structure information is only used to help speed the dissemination up or save the energy consumption. While in the hierarchy-schemes, nodes are divided into clusters with a cluster head for each. The cluster heads therefore form a backbone network to get data preferentially and then disseminate data to the cluster members in their own clusters.

4.1 Plain-Structure Schemes

The authors of [23] proposed two schemes for alleviating broadcast storm problem, leveraging the location information. The first one is the distance-based scheme. In this scheme, the decision of rebroadcasts depends on the relative distance between nodes. Fig.5 is an example to illustrate the definition of the additional coverage in [23]. The dark area is the additional coverage of node B. Denote the distance between A and B as d. If d is very small, then there will be little additional coverage that B's rebroadcast can provide. The additional coverage will be larger when d becomes larger. The relationship between d and the additional coverage area $S_{\rm add}$ is:

$$S_{\rm add} = \pi r^2 - 4\int_{d/2}^{r} \sqrt{r^2 - x^2}dx \geqslant S_T, \qquad (2)$$

where r is the transmission range of the radio. Hence, if d is larger than some threshold D, then the additional coverage will be larger than some threshold which can be regarded as beneficial. Then node B will rebroadcast the packets from A.

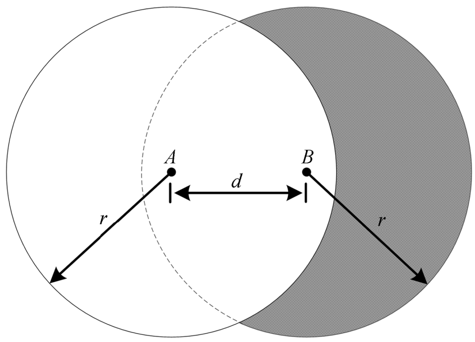

Fig.5. Additional coverage[23].

The second scheme is the location-based scheme. This scheme also follows the principle that covering more additional coverage. But it can accurately calculate $S_{\rm add}$ by employing some powerful tools such as global positioning system (GPS) to get the exact locations of the nodes. When a node has more than one neighbor, the distance-based scheme has to use the minimum distance to calculate $S_{\rm add}$ by (2) since there is no direction information available. While in the location-based scheme, the distance and direction information is available to calculate $S_{\rm add}$ when the node is influenced by more than one neighbor. Then if $S_{\rm add}$ is larger than the threshold, the node will broadcast. Otherwise, it drops the packet.

Infuse[37] is a reliable data dissemination protocol tailored to Time Division Multiple Access (TDMA) protocols. It requires neighborhood information (successors in the east/south direction), which need localization to obtain the necessary information. The time is divided into slots and each node in the local area takes an exclusive slot. The location information is used for dividing the neighboring nodes as predecessors and successors. Then the node will listen to a subset of predecessors and successors to reduce the radio on time. The dissemination is initiated by the start-download message from the sink. When a node receives this message, it prepares the dissemination by initializing the flash and notifying the current program. After receiving the data, the node will forward the data in its own time slots. The nodes that turn on the radio in a time slot will receive the data transmitted in this time slot. Although TDMA is collision-free, messages can be lost due to the errors caused by channel fading and external interference. Hence, Infuse also has the error recovery algorithm which is a go-back-n based recovery algorithm. Suppose the window size is n, then the node will not send packet d_i until the ACK of packet d_{i-n} is heard.

Freshet[38] was proposed for optimizing the energy during data dissemination. It shares many design principles with Deluge and MNP. However, it uses network topology information to optimize the energy. Freshet achieves the energy efficiency by aggressively turning off the nodes' radio when the data transmissions are not likely to happen in the neighborhood. Before the dissemination of the real data, the sink firstly broadcasts a small packet with the topology information to the whole network. Each node learns the time that data may be transmitted in its neighborhood based on this topology information. Hence, a node can save energy by scheduling itself to sleep when the dissemination is far away. Besides, it allows nodes to receive pages out of the sequence to speed up the dissemination, if multiple data sources are available.

4.2 Hierarchical-Structure Schemes

The authors of [23] proposed a hierarchical-structure scheme called cluster-based scheme. The topology information is used to construct the clusters. Initially, each node regards itself as a cluster and then merges with other clusters. The nodes which can communicate with every node in a cluster form the set of the candidate cluster heads. Then the candidate with the minimum ID will be elected as the cluster head. The mobility of nodes is also being considered. When two cluster heads meet, then the one with smaller ID will win the head position and the other one will give up the head role. Fig.6 shows an example of the cluster structure. In this cluster-based scheme, only the cluster heads and gateway nodes rebroadcast packets while the member nodes keep receiving useful data without rebroadcast.

Sprinkler[39] is a reliable data dissemination protocol that leverages the network topology information to construct a hierarchical structure for speeding up dissemination and avoiding unnecessary energy consumption. A subset of nodes are selected as the stationary senders. Every node in the network is either a stationary sender or a neighbor connected to one of the stationary senders. This structure is equivalent to the connected dominating set (CDS) in a graph. To get the structure with the minimum number of stationary senders is to compute the minimum CDS problem which is NP-hard. Sprinkler provides a low complexity CDS algorithm for the sensor nodes. After obtaining this hierarchical structure, Sprinkler divides data dissemination into two phases: streaming phase and recovery phase. In the streaming phase, only the nodes in the CDS transmit packets. In the recovery phase, the non-CDS nodes send NACK to the CDS nodes asking for the missing data. Sprinkler also avoids the hidden terminal problem by using TDMA.

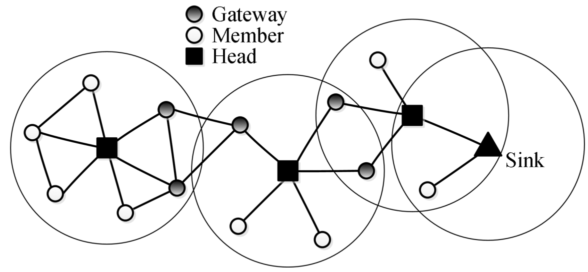

Fig.6. Example of a clustered structure.

Firecracker[40] works in a similar way to Sprinkler. It uses a combination of routing and broadcasting to rapidly disseminate the data. It also has two phases. In the first phase, the source node sends the data to some distant nodes in the network based on routing. The nodes traversed by the data form the backbone network. The backbone nodes in Firecracker are the nodes in each corner or randomly selected. Once these distant nodes get the data, Firecracker goes into the second phase. In the second phase, broadcast-based dissemination begins along the paths formed in the first phase, like a string of firecrackers. The nodes in the backbone network will broadcast the data to other nodes.

CORD[41] is a reliable data dissemination protocol dedicated to the bulk data. Similar to the above three hierarchical structure schemes, CORD also constructs a dedicated hierarchical structure and disseminates the data in a two-phase manner. In the first phase, data is disseminated to a subset of nodes called core nodes that form a connected dominating set. Then the core nodes broadcast the data to other nodes. The dissemination among the core nodes can be implemented by the schemes similar to Deluge and MNP, which disseminates data by reliable hop-by-hop forwarding. Besides, CORD also designs a sleep scheduling algorithm in conjunction with the two-phase dissemination to save the energy.

OAP-SW[42] is a reliable dissemination protocol that leverages the small world features to improve the performance of data dissemination. The small world characteristic means that there exist shortcuts from the sink to the other parts of the network. The idea behind OAP-SW is similar to Firecracker, which firstly deliveries the data to some nodes spreading the whole network. Then all these nodes disseminate the data simultaneously to speed up the process. However, OAP-SW adds some nodes with more powerful hardware as the endpoints of the shortcuts, forming a heterogeneous network. Then the placement of endpoints of shortcuts is solved by designing the approximation algorithm of the minimum set cover problem.

5 Other Techniques Used in Data Dissemination

5.1 Segmentation and Pipelining

Most data dissemination protocols (e.g., [33-38, 41-43]) take advantage of pipelining to exploit the spatial multiplexing. Segmentation is a technique coupled with pipelining. A data object is divided into several pages, each of which contains a fixed number of packets. For example, one page contains 48 packets in Deluge[33].

The data management hierarchy specified in [33] is shown in Fig.7. The data object is segmented into P pages, each of which has N packets. Instead of completely receiving the data as a whole before forwarding, a node performs as a forwarder after it receives only one complete page. Deluge leverages this data management hierarchy to take advantage of pipelining for speeding up the dissemination. Existing work usually follows this hierarchy to manage the data.

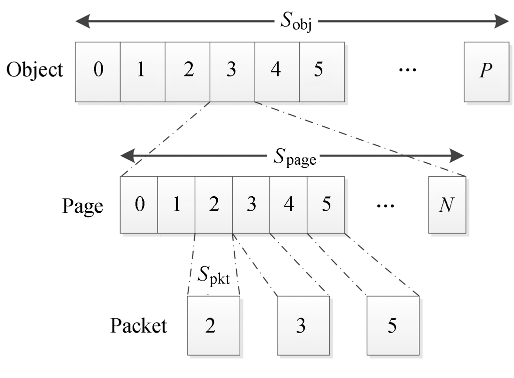

Fig.7. Data management hierarchy[33].

In order to realize the full benefit of spatial multiplexing, the transmissions in different places should be performed simultaneously. But it is required that the simultaneous transmissions do not interfere with each other. In pipelining, existing work assumes that the concurrent transmission of two pages must be at least three hops away to avoid collisions. In Fig.8, a simultaneous broadcast of node 1 and node 4 will not collide, speeding up the dissemination.

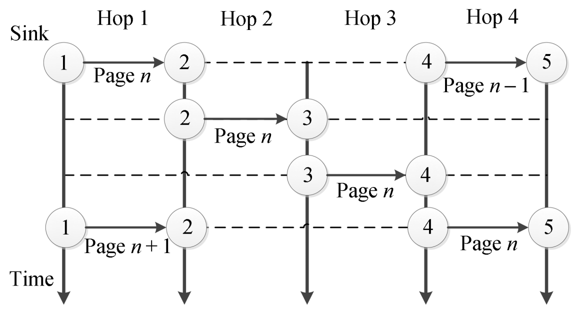

Fig.8. Pipelining.

5.2 Coding Technique

Another promising technique can be employed in data dissemination is coding. In the non-coding schemes, we have to maintain a receiving vector on the receiver to record which packets are received, and a to-do vector on the sender to record which packets are requested by the receivers and needed to be broadcasted. This is the root cause of the need for NACK or ACK in existing work. Hence, if the sender knows the packets it sends out must be useful to some receivers without knowing which particular packets are lost, part of the negotiation can be cut down and the efficiency of dissemination can be improved significantly.

Coding techniques help us to accomplish this longing property. Commonly, the coding techniques used in data dissemination must be rateless since the status of different packets is equivalent in a rateless coding scheme. The packets are encoded into data blocks that are linearly independent. When the packets are lost, there is no need to know which particular packets are lost. The sender just keeps sending the encoded packets to the receivers until enough packets are received for decoding.

SYNAPSE[44] is a rateless coding-based data dissemination protocol. It improves the efficiency mainly by levering a rateless coding technique in the error recovery phase. The adopted coding technique is Digital Fountain Codes[45], which has a low computational complexity. The encoding and decoding are carried out by the exclusive OR (XOR) operations. After encoding, a negotiation scheme is exploited to do the dissemination. Redundant encoded packets will be directly transmitted for the fast error recovery. If there are still some receivers that cannot decode the packets, the hybrid ARQ is adopted. Different from the technique of NACK/ACK in previous work that specifies the receiving vector, SYNAPSE only requires the receiver specifies the number of the additional packets to perform decoding.

Rateless Deluge[46] proposes two schemes that use the coding techniques. The first one is rateless Deluge, which uses a rateless coding technique to disseminate data. The second one is ACKless Deluge, which further adopts the Forward Erasure Correction (FEC) mechanism to eliminate the need for the control packets. ACKless Deluge transmits the extra encoded packets in advance that reduce the demand for the packet retransmissions with a high probability. Rateless Deluge exploits the random linear coding which is rateless and has no decoding inefficiency. The random linear coding is encoding a data image with k segments into the m linear combinations, where $m > k$. Then the sender transmits the encoded packets. The receiver that receives any k messages can recover the original data image by solving the corresponding system of linear equations.

The authors in [47] proposed an XORs encoding decision algorithm to minimize the number of transmissions for energy saving. It is designed for the duty cycled WSNs. The authors studied the effectiveness of the sleep scheduling on energy saving and then how to decide whether the current sleep scheduling is effective or not based on a threshold.

The authors of [48] provided an analytical upper bound of the completion time in a general network topology. The result shows that the completion time of the methods with network coding is between $O(N)$ and $O(N^2)$ where N is the number of nodes in the network. However, only the network transmission latency is considered when modeling the completion time. The time spent on encoding/decoding is not considered.

5.3 Constructive Interference

Recently, there are some researches that focus on leveraging the interference instead of avoiding it.

Glossy[49] is a novel flooding architecture for WSNs. It exploits Constructive Interference (CI) of IEEE 802.15.4 symbols for the fast network flooding. It is discussed in the previous sections that classic flooding is prone to have the broadcast storm problem. One possible approach is to schedule the broadcasts to make them interference free. However, to design such a schedule is an NP-complete problem[50]. On the other hand, it is shown in [51] that the so-called capture effect[52] can be exploited in WSNs. As for capture effect, also called co-channel interference tolerance, the receiver is able to correctly receive a strong signal from one sender in spite of the significant interference from other senders.

However, the capture effect only happens occasionally. Hence, Glossy analyzes the underlying reason of CI and intentionally makes it happen beneficially. Glossy requires simultaneous transmissions of the same packet to make them interfere constructively. Then the artificial capture effect helps the receiver to decode the packet. Hence, Glossy disseminates data as follows. The source node initially broadcasts the first packet. Neighbors retransmit the packet right after receiving the packet to meet the conditions of CI which are 1) simultaneous transmissions; 2) the same packet. Then the source continues flooding out the data packets after a certain safety time period which is enough for the previous packet to flood out the communication range. By this way, Glossy can disseminate the data with a quite high reliability without any control overhead involved in the process.

6 Performance of Existing Protocols

The performance of data dissemination in WSNs is crucial to the stability and lifetime of the systems. The reason will not be stated in details since it has been explained in Subsection 2.2. The evaluation approaches are usually: 1) testbed; 2) simulation. In this section, we introduce the performance metrics and then discuss the advantages and disadvantages of different schemes.

6.1 Performance Metrics

The performance metrics are based on the data dissemination requirements.

Reliability is the basic requirement as well as the essential performance metric in data dissemination. Reliability is usually measured by the ratio of the size of data that nodes in the network received to the size of whole data that all nodes need to receive. For example, if the size of disseminating data is 1 KB and there are 500 nodes in the network, then the size of data that all nodes need is 500 KB. If the size of received data of all 500 nodes is 490 KB according to a protocol, then the reliability of this protocol is 98%. Even though sometimes the reliability is not strictly required to be 100%, the 100% reliability is a desired performance. Besides, it is usually required to be nearly 100% with a high probability even if not 100%.

The negotiation-based schemes can achieve a 100% reliability since the negotiation process makes sure that every node gets the latest data eventually in finite time. On the other hand, the non-negotiation schemes cannot achieve the 100% reliability in a given time period because the lack of negotiation makes nodes with missing data keep silent rather than actively ask for the missing data.

Completion time is crucial to the overall system performance. Based on the time-efficiency requirements, dissemination should be completed as quickly as possible. Completion time is generally defined as the time period from the time that the initial node sends out the first packet to the time that the last node in the network completes sending or receiving the packets. In the negotiation-based schemes, the time that the last node receives all the data is the end of the dissemination. In the non-negotiation schemes, the time that the last node finishes broadcasting the data is the end of the dissemination.

Energy consumption is always the key concern in WSNs. A minimal amount of energy should be used in order to lengthen the network lifetime. The energy consumption of some related operations on a Mica2 node is shown in Table 1[53]. We find that the current draw of the radio is much larger than the other activities of nodes. Hence, to meet the energy-efficiency requirement, what we must carefully deal with is the radio-on time since the negotiation strategy needs nodes to turn on their radios for overhearing control messages.

Table 1. Energy Consumption on Mica2 Platform[53]

Operations	Power Consumption (nAh)
Read a data block from EEPROM	1.261
Write a data block to EEPROM	85.449
Send one packet	20.000
Receive one packet	8.000
Idle listen for 1 ms	1.250

Memory usage needs to be planned. The limited memory resources on a node require the dissemination schemes should use a limited memory. During dissemination, the memory of certain size is required for storing dissemination data and other information. Generally speaking, the protocols that adopt segmentation require a small size of the memory. Because the dissemination in segmentation is page by page, the required memory is the size of one page and the size of memory for storing other information; while without segmentation, the nodes have to store the whole data in memory; otherwise, the node must read the data from the flash storage when it needs sending out the data that are not in memory.

6.2 Performance Comparisons

According to the taxonomy of this survey, we compare different schemes reviewed in this survey. The detailed performance comparisons of these schemes are omitted here since the experiment results may be different due to the different experimental or simulation settings in different studies. We only give some general comparisons as follows.

Structure-Less Schemes vs Structure-Based Schemes. Structure-less schemes can be employed in a large-scale system easily. They are adaptive to the dynamic networks with a good scalability; while the structure-based schemes obviously cannot fit for dynamic networks since each change of the network environment results in a reconstruction of the dedicated structure. Even though structure-based schemes reduce the control overhead during the dissemination process, they introduce the overhead of maintaining the dedicated structure.

Non-Negotiation Schemes vs Negotiation-Based Schemes. Non-negotiation schemes do not have the overhead of control messages brought by the negotiation strategy. They disseminate data quite quickly. Their disadvantage is that the reliability is not guaranteed. If a high reliability is wanted, the ARQ mechanism is needed. However, the ACK/NACK messages will incur the ACK implosion problem and the broadcast storm problem. On the other hand, negotiation-based schemes sacrifice time-efficiency for reliability. The negotiation strategy effectively eliminates the redundant transmissions and guarantees the reliability. But negotiation is time-costly. In our recent experiment, the control time incurred mainly by negotiations takes around 70% of the total completion time. At the same time, the negotiation also introduces some additional transmissions of the control messages.

Plain vs Hierarchy. The plain structure based schemes have low cost of acquiring the topology information or location information. Some of these schemes only need the local structure information. The structure is easy to construct and maintain. Compared with the plain ones, hierarchy can speed up the dissemination process in the relatively stationary networks but not in the dynamic networks. If the networks are dynamic, then hierarchical structure based schemes need to reconstruct the disseminating structure once the network changes. Hence, the cost of constructing structure may be higher than the overhead of non-structure based approaches.

Whole Image vs Segmentation. When the data block is of a large size, disseminating the whole data hop by hop takes a long time. By segmenting and pipelining, the completion time will be much shorter. Except some early studies, this technique is widely adopted in the existing work.

The detailed comparisons are shown in Table 2 and Table 3. The results are summarized from the evaluation results of the corresponding literature. These results are consistent to our analysis in Sections 3 and 4. For example, even though the reliabilities achieved by different flooding methods are different, they are lower than the achievable reliabilities of negotiation-based

Table 2. Performance Comparison of Structure-Less Schemes

Protocol		Reliability	Completion Time	Energy Consumption
Non-Negotiation	B-Flooding	No guarantee	Short	Small
	P-Flooding[23]	No guarantee	Short	Small
	C-Flooding[23,26]	No guarantee	Short	Small
	Trickle[28]	No guarantee	Short	Small
	Smart Gossip[29]	No guarantee	Short	Small
	Gossip[27]	No guarantee	Short	Small
Negotiation-Based	SPIN[30-31]	Guaranteed	Moderate	Large
	MOAP[32]	Guaranteed	Moderate	Large
	Deluge[33]	Guaranteed	Moderate	Large
	MNP[34]	Guaranteed	Moderate	Moderate
	ECD[35]	Guaranteed	Moderate	Large
	ReMo[36]	Guaranteed	Moderate	Moderate

Table 3. Performance Comparison of Structure-Based Schemes

Protocol		Reliability	Completion Time	Energy Consumption
Plain-Structure	DB-Flooding[23]	No guarantee	Short	Small
	LB-Flooding[23,26]	No guarantee	Short	Small
	Infuse[37]	No guarantee	Short	Moderate
	Freshet[38]	Guaranteed	Long	Small
Hierarchical-Structure	Cluster-Flooding[23]	No guarantee	Moderate	Moderate
	Sprinkler[39]	Guaranteed	Long	Very small
	Firecracker[40]	Guaranteed	Long	Moderate
	CORD[41]	Guaranteed	Long	Small
	OAP-SW[42]	Guaranteed	Long	Moderate

schemes due to the absence of the ARQ mechanism adopted in negotiation-based schemes. Literature [53] and [54] also give some comparisons about the related protocols. Besides, in [55], the completion time of negotiation-based schemes is modeled and measured for the further understanding.

We adopt the reduction factor to compare the completion time of some representative existing protocols. Deluge is the default dissemination protocol in TinyOS, which is widely applied in many real WSN systems. Thus we use Deluge as the baseline of the comparison. Table 4 presents the reduction factor achieved by each protocol compared with Deluge. The protocols listed in the table have the same optimization objective: completion time. All of these methods are negotiation-based schemes. The optimal completion time is bounded by the negotiation processes. Emerging techniques such as constructive interference may bring significant improvements in terms of completion time.

Table 4. Comparison of the Completion Time of Some Existing Protocols

Protocols	Number of Nodes	Data Size (KB)	Reduction Factor
MNP[34] (2005)	100	5.6	1.21
Rateless Deluge[46] (2008)	20	0.7	1.47
CORD[41] (2008)	33	20.0	1.04
ReXOR[56] (2011)	16	4.0	1.53
ECD[35] (2011)	25	10.0	1.44

7 Future Directions

7.1 Hybrid Schemes

In the existing literature, different categories have definite boundaries and no trade-off has been analyzed before. In this survey, we analyzed the trade-off between different categories. The hybrid schemes, combining non-negotiation and negotiation-based schemes, were discussed and analyzed. We regard hybrid schemes as a promising direction to improve the efficiency in the existing working framework.

We notice that the negotiation scheme, although essential for guaranteeing a high reliability, brings additional control overhead. We conduct an experiment with two TelosB nodes transmitting 10 KB data using Deluge. The nodes are placed 5 meters away, with a 0 dBm transmission power. The result shows that the time spent on negotiation contributes to 71% of the total dissemination time.

This gives us a hit that the negotiation may be too costly to get high reliability. We perform a confirmatory experiment to analyze the performance of non-negotiation and negotiation-based schemes. We use probabilistic flooding as the representative of non-negotiation schemes and Deluge as the representative of negotiation-based schemes. We place 40 TelosB nodes on an indoor testbed, forming a grid network topology. The transmission power is set to the minimum for obtaining the multi-hop dissemination.

Fig.9 shows the time-reliability curve for the two classes of schemes. We see that: 1) For a small number n, flooding cannot achieve a high reliability. Hence, negotiation is indispensable to guarantee the 100% reliability; 2) However, for a certain level reliability, e.g., $< 30\%$, flooding (with $n = 1, 3$) has a much shorter completion time compared with the negotiation-based dissemination; 3) For a high level of reliability, e.g., $> 80\%$, flooding (with $n = 15$) has a longer completion time than Deluge.

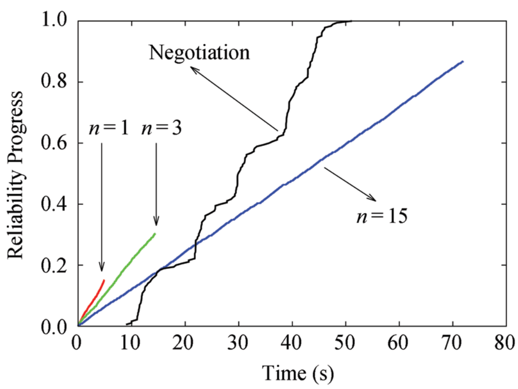

Fig.9. Reliability progress.

We summarize the observations as follows. 1) For certain level of reliability, probabilistic flooding often has a much shorter dissemination time. This is because probabilistic flooding does not involve any control message during the dissemination. 2) On the other hand, for a higher level of reliability, probabilistic flooding with increased flooding times n becomes inefficient because the blind flooding without feedbacks tends to cause a large amount of redundancy. In contrast, the use of negotiation with explicit requests for the missing packets in this phase will effectively reduce the redundancy.

When designing a hybrid method, the transition between two schemes should be carefully decided. For example, one simple hybrid scheme is flooding n times and then disseminating the remaining data by negotiation-based schemes. Then a key challenge is to determine when and how nodes transit between the two schemes (flooding vs negotiation). A bad transition point may result in longer dissemination time. For example, if the node turns to negotiation-based schemes after 15 times flooding, then the completion time is longer than the completion time of negotiation-based schemes. While a smaller flooding times n may result in insufficient fast dissemination. One possible solution is modeling the time-reliability models of the two schemes[57]. The reliability progress of these two schemes in the unit time could be modeled and calculated. Then the scheme that can achieve more reliability progress in the unit time should be adopted.

7.2 Constructive Interference

Glossy is a recent work that designs and implements a fast flooding scheme that leverages constructive interference. Constructive Interference (CI) eliminates the collision without any control message involved in. By this way, it realizes the concurrency of transmissions in local areas, which is impossible in existing working architecture. Concurrency is a desired property in data dissemination. It can help reduce the completion time. Hence, CI is a very promising technique that can be adopted in data dissemination.

However, the application of CI also has some challenges: 1) there is no reliability guarantee mechanism provided in CI; 2) CI is too fast to make the error recovery done timely; 3) CI requires more than one reliable transmitter transmits the same packet at the same time, while the reliable links in real deployment may be too few to create efficient constructive interference phenomenon.

We envision that CI could be integrated with coding techniques to further improve the efficiency of error recovery procedure. Time-efficiency can be improved by CI and further improved by coding technique together with forward error correction (FEC) which predicts how many redundant packets needed by the receiver to decode the data. By FEC, the data can be reliably disseminated to the whole network with a high probability with the absence of ARQ mechanism. Another direction to overcome the challenges 1) and 2) is to add ARQ mechanism to CI. By this means, CI needs to design the strategy of sending back ACK/NACK by constructive interference or by correlated ACK/NACK.

For the challenge 3), the first and the least wanted method is to place additional nodes to improve the link qualities of the poor areas. There is a recent work called Wireless Bus[58]. In this work, the network is configured as a bus to do data transmission Patching it with the reliability guarantee mechanism is another proposal to do data dissemination by leveraging CI.

7.3 Open Issues

Security. Security should be considered in some application systems such as military monitoring. However, the research on security in data dissemination is limited. The traditional encryption algorithms are too complex to operate on nodes. Hence, some researchers propose some simple alternative methods. The authors of [59] made changes to the file system management, reboot mechanism, and bootloader on iMote2 sensor nodes to protect the system from reprogramming by an unauthorized third party. The authors of [60] proposed a method to achieve confidentiality in the multi-hop data dissemination. The data are protected to avoid the spurious data images from the adversary. However, these methods still need many resources and adopt complicated algorithms. To make real deployed systems secure during data dissemination, it needs more effort to make the secure methods easy and effective to use.

Heterogeneous Networks. Heterogeneous networks should be considered when performing data dissemination since the application systems deployed in nowadays tend to have cooperation among the heterogeneous networks. However, data dissemination among the heterogeneous networks is not well studied. The authors of [61] studied the code dissemination problem in heterogeneous WSNs. They formulated the problem as a minimum non-leaf nodes Steiner tree problem and proposed a multicast protocol HSR with an approximate ratio $\ln|R|$, where R is the set of all destinations. Sprinkler[39] can also be applied to heterogeneous networks. However, these researches treat the heterogeneous networks as separated networks. When performing data dissemination, they firstly separate nodes belonging to different networks into different sets and then disseminate data in each separated network. This framework is effective but inefficient. Therefore, a possible future direction of improving data dissemination protocols in heterogeneous networks is reducing the overhead of separating the heterogeneous networks.

8 Conclusions

Data dissemination is a crucial building block for many other applications. For example, localization[10,62-66] needs dissemination to initiate the localized targets. Time synchronization[12,67-68] is another fundamental service needing disseminations to announce the global time. Diagnosis[13,69-70] uses dissemination to start the diagnosis and deliver the solutions from the sink.

During the long lifetime of a WSN system, it is necessary to fix bugs, reconfigure system parameters, and upgrade the software in order to achieve reliable system performance. Data dissemination over multi-hops is desired to facilitate such tasks. Based on whether or not a dedicated structure is used in data dissemination, existing approaches can be divided into two categories: structure-less and structure-based schemes. Structure-less schemes can be further divided into negotiation-based and non-negotiation schemes by whether or not a negotiation mechanism is used. Structure-based schemes are divided into plain-structure schemes and hierarchical-structure schemes. We in depth elaborated and compared these schemes. We reviewed the requirements and challenges of data dissemination in WSNs, and introduced some related and emerging techniques such as coding and constructive interference. We also discussed the performance metrics of data dissemination and present comparisons of different schemes. Finally, we discussed the possible future directions and some open issues based on the emerging techniques.

Even though there is plentiful literature, there is still space for further improvement in the existing framework. Besides, some emerging techniques are very promising for changing the working framework of data dissemination. There are still some open issues that need further investigation to design an efficient protocol that can be widely adopted in real deployed systems.

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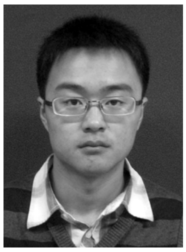

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