A Survey on Reliable Transmission Technologies in Wireless Sensor Networks

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Abstract. Reliability is an important issue in wireless sensor networks (WSNs). Reliable transmission of data in WSNs is the basic of successful network operation. In this paper, we firstly define the evaluation methods for reliability in WSNs in terms of evaluation metrics and recovery ways. The technologies to improve reliability for WSNs are summed up in several classifications: retransmission, redundancy, hybrid method and some newly emerging technologies. Some typical protocols are stated and analyzed. Also we compare these technologies in several aspects as the direction for future research.

Keywords: Wireless sensor networks · Reliability · Redundancy · Retransmission · Network coding · Cooperative transmission

1 Introduction

Wireless sensor networks (WSNs) are used in many occasions for its excellent features, while more and more applications have put forward higher requirements to the reliability of data transmission in WSNs, such as in industrial monitoring where the data should be reliably transmitted to the control center so that the workers can make decisions and take actions accurately. The reliability of WSNs can be easily decreased due to the features of WSNs, like the unstable wireless link, vulnerable sensor nodes, the deployment of nodes and other environmental reasons. Therefore, the scholars have already proposed different ways to solve this problem in various aspects, for preventing the data from being altered or stolen and reducing the possibility of transmission loss in bad conditions. In this paper, we summarize some of the researches in the reliability area and make a compositive comparison between them.

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In Sect. 2, we classify the reliability evaluation method, which consists of evaluation metric and recover way. In evaluation metric, the methods are divided into packet-based and event-based, while the recover ways are separated to two types: end to end and hop by hop. In Sect. 3, we divided the reliability technologies into four types: retransmission-based, redundancy-based, hybrid and other methods. We select some typical protocols and give an outline of these methods, additionally, analyze the advantages and disadvantages. In Sect. 4, a general comparison is conducted. Finally, we make a conclusion in Sect. 5.

2 Evaluation Method of Reliability

2.1 Evaluation Metric

We classify the reliability of data transmission to "packet reliability" and "event reliability" according to metric classification. The purpose of packet reliability is to ensure that all the data sensed which carried with packets from all relevant sensor nodes are transmitted to the receiver reliably. Packet reliability requires that all the packets carrying with perception information sent by all sensor nodes can be reliably delivered to the sink node. Event reliability only needs to ensure that the sink node is able to get enough information about an event on time, and does not need to ensure all the packets must be transmitted to the sink node. Therefore, event reliability is more suitable as the measurement indicators of transmission reliability in some applications of WSNs, which only have to ensure that the receiver receives the user's necessary information, rather than all sensor data packets.

2.2 Recovery Method

WSNs with limited bandwidth resource and low storage capabilities of sensor nodes will be easily block up in the network; at the same time, wireless communication has high bit error rate because of environmental impact. In order to meet the requirements of reliability in the network, the loss data packets can be recovered by end to end or hop by hop.

End to end method also called connection-oriented mechanism, of which only have two end points to ensure the reliability. That is to say, only recover packet loss in the source node, and intermediate nodes should simply be responsible for transmitting data between source and destination nodes.

In the recovery mode, the packet loss recovery must be carried out hop by hop, and finally the data packets can be transmitted to the sink node reliably. Hop by hop mechanism can be used as a guide for data transmission links, because each hop has to ensure the reliability. In other words, every hop from source node to destination node has to ensure the reliable transmission of data, in order to achieve the reliability of the whole transmission.

We classify the reliability assessment methods by introducing a three-dimensional reference model, as shown in Fig. 1.

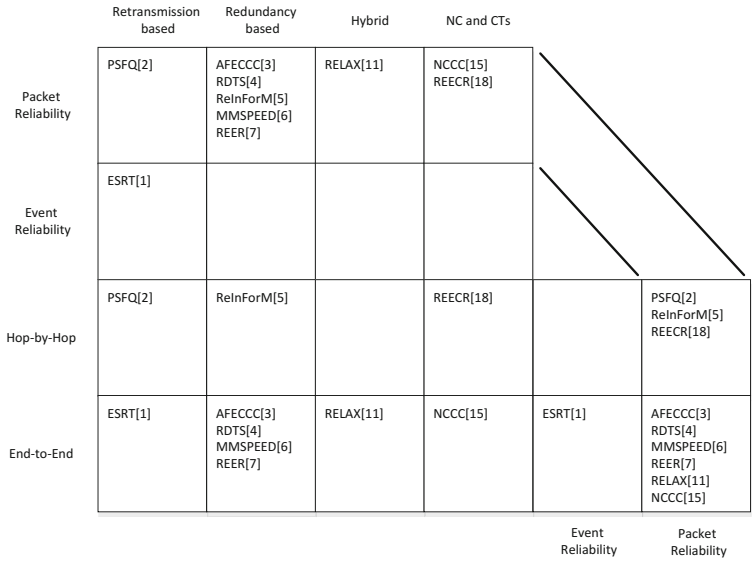

Fig. 1. Three-dimensional (3D) reference model for research in reliability of WSNs

3 Reliable Transmission Technologies in WSNs

3.1 Retransmission

The retransmission mechanism in wireless devices is that when sending node cannot receive the ACK in specified time, it will resend the data until receive the ACK successfully or approach the attempt limit.

Event-to-sink reliability is one of the most significant features of reliable transport in WSN. Literature [1] proposed a new transmission protocol with reliability and congestion control implemented in sink node - the event-sink reliable (ESRT) protocol. ESRT covers a congestion control component. The sink node in the network can inform the source node to adjust upload data rate adaptively through the radio according to current network condition. Therefore, we can ensure the event reliability without causing congestion as well as achieve the double goals of data transmission reliability and energy saving. In addition, the ESRT protocol operations can also be extended to allow multiple events in the case of transmission. Based on the proof of theoretical analysis and simulation experiments, ESRT protocol has higher data transmission accuracy and greater network coverage area and stronger local feature extraction ability compared with reliable transmission protocols. Regardless of the initial state of the network, the ESRT protocol can enable it to achieve the optimal state. However, this protocol belongs to typical event-detection application in WSNs, which cannot guarantee the success of end-to-end data transmission. At the same time, sink node in ESRT adopts the broadcast way to inform the source node to adjust frequency adaptively which aggravated the nodes' loads around sink node.

A certain packet loss rate is acceptable in the data flow that from the source node to the sink node in WSN, while the data flow for the control or management in the opposite direction is very sensitive. Therefore, the new reliable transmission PSFQ [2] protocol referred to "Pump-slowly, fetch-quickly" was proposed. "Pump-slowly" means nodes in the network broadcast data to the neighboring nodes at a slow speed. "Fetch-quickly" refers to in case of packet loss, nodes request neighboring nodes to retransmit for loss recovery. According to the simulation and experiment results, PSFQ is superior to other traditional technology. Even in the case of high packet loss rate, it can maintain the normal operation of the network. This protocol has obvious advantages in fault tolerance, communication overhead and transmission delay. PSFQ is mainly applied for the sink node sending query and control messages to the source node without a complex routing infrastructure. Furthermore, this protocol cannot adapt to the change of the network.

3.2 Redundancy

3.2.1 Forward Error Correction

Protocol [3] provides some evidence to prove the bit error rate of low energy wireless communication channel can change smoothly in order to adjust the magnitude of FEC codes dynamically. At the same time, an adaptive FEC code control algorithm called AFECCC is proposed and its performance is evaluated in a variety of communication channels and real wireless sensor networks. This algorithm can adjust the size of the FEC code dynamically according to the instructions of the received confirmation packet. Rising to a higher FEC level in the case of data packet loss, otherwise reducing to lower level of FEC by MIAD—multiplicative increase additive decrease. About the residence time in each level, it is determined by the success ratio before dropping to a lower level dynamically. In other words, AFECCC uses the level more frequently the longer time it will stay at this level. The simulation experiments show that the performance of AFECCC is better than that of any static algorithm as well as two earlier hybrid ARQ/FEC algorithms. How to determine the variables of AFECCC automatically based on the network environment is still a challenging issue.

The nodes in typical WSNs collect information by connected sensors, and the data is transmitted to the base station or sink node hop by hop. The effect of transmission is easy to be affected by the environment, therefore, the quantity of data packets transferred to the sink node successfully determines the reliability of the data transmission. Paper [4] proposed a more efficient mechanism, RDTS, which is more effective than previous retransmission and information redundancy. The main idea of this protocol is to calculate the quantity of redundant data packets and find the methods of eliminating the intermediate nodes code according to the quality of hop by hop connection, so as to ensure the reliability of the hop-by-hop transmission. Using of RDTS has several advantages: first it can reduce the redundant data significantly, results in saving energy and extending the life cycle of the network. In addition, the authors adopt the useful feature of systematic erasure coding that performs partial coding, which solve the problem of coding overhead.

3.2.2 Multi-path Routing

Literature [5] introduces a protocol called ReInForm. Provisions of this protocol for every data packet need multiple copies and then transmit them from source to sink via multiple paths, so data can meet the required reliability in the process of transmission. And the referenced degree of redundant backup data is decided by the desired reliability, local channels' condition, the information that provided by neighbor nodes altogether; after that the source node will select the next hop by the hops between neighbor nodes and sink nodes, and then distribute the backup data packets by proportion. Furthermore, repeat the above steps until the data packet has been transmitted to the sink node. With the feature of this mechanism, it is possible to use all possible paths efficiently and to achieve a high efficiency of load balancing. To sum up, this protocol makes use of multiple backup data packets to improve the transmission probability of end-to-end data and reduce the cost of transmission in order to approach the desired reliability.

Protocol [6] proposed a new data transmission agreement in WSN called MMSPEED, which provides the guarantee of QoS through the real-time differences and reliability services. In terms of real time, this protocol provides a variety of network speed options so that different traffic types can select the appropriate speed dynamically. In terms of reliability, this protocol adopts the multiple paths to transmit data packet according to the successful transmission rate of end-to-end. Network layer and MAC layer are connected with this protocol and then achieve it by localization method. MMSPEED can mix periodic and non periodic data in the network without global network information through a dynamic compensation method to adjust the reliability of each node. Therefore, MMSPEED can adapt to large-scale sensor network's requirements dynamically. Based on the simulation on J-SIM and the comparison with the SPEED protocol, the results show that MMSPEED protocol can meet the both requirements of real-time and reliability, furthermore, it can improve the capacity of network under different requirements significantly. However, the disadvantage of this protocol is that WSNs with MMSPEED protocol has higher energy consumption which will shorten the lifetime of the network.

A robust and energy efficient multipath routing for WSNs was proposed in this [7] protocol which called REER. In the establishment of the routes, it takes the node's residual energy, available buffer size of the nodes and signal to noise ratio (SNR) into account in order to select the best next hop node. After finishing the path detection, BEER proposes two kinds of flow distribution mechanism: one is using the path that has been found to transmit data packets, and it will be replaced by another backup path when this one exceeds a certain threshold. Another mechanism is distributing the transmitted information into fragments of the same size, increasing the error correcting codes that based on XOR. This mechanism increases the reliability of the transmission to the destination nodes by multiple routes, at the same time, it will not cause much delay.

Simulation results show that the REER can reduce the energy consumption and data transmission delay as well as improve the transmission rate of data compared with Diffusion Directed and N-to-1 routing.

3.3 Hybrid Scheme

In [9], an error control schemes by using cross-layer methodology was proposed. Specifically, it did the research about the effect of multi hop routing path and the broadcast nature of wireless communication, the purpose is to be able to count the energy consumption, PER and the potential factors of the error control theory equably. This cross-layer theory has taken routes' selections, media connection and the effect of physical layer into account which becomes a comprehensive comparison of FEC, ARQ and hybrid ARQ theory. The research results of hybrid ARQ theory and certain FEC codes show that after extending the length of each hop, energy consumption and the potential target data packet error rate (PER) will increase compared to ARQ. However, when the network density increases, the FEC codes will have much more advantages. On the other hand, ARQ is better than FEC in the aspect of value in various end-to-end distance and the target PER. In summary, this thesis analyzes when is the best time to use FEC, ARQ or hybrid ARQ scheme.

In [10], the author made a comparative theoretical study on the transmission reliability of retransmission and redundancy. And in order to fully study their advantages and possibilities, a comparison between the energy efficiency of retransmission and redundancy was also made. The authors present a simple and achievable analysis model to analyze the probability of arriving packets and the average energy consumption in terms of retransmission and redundancy. According to the proposed model, the comprehensive effect of the two methods in reliability and energy efficiency can be measured in the aspect of quantity, where the results show that redundancy has the better flexibility of the data packet loss, from one hop costs a ulp of 0.5 to multihop cost a ulp of 0.07. Compared with effective retransmission, the redundancy can still achieve reliable transmission in the loss of packets at low frequency and smooth situation. However, the advantage of this model will be weakened in the case of hop increase, thus it is very important to consider the balance between reliability and energy efficiency. About future research direction, the author will break down the redundant information association in order to overcome the continuous error or the high data packet loss, and combine the two methods together.

In [11], the author proposed the RELAX protocol. The multipath routing protocol of energy efficiency in WSNs can recover from the path failure and achieve the load balance. It can achieve the load balance of flow distribution by using the nodes' battery power efficiently through a set of node-disjoint paths. This protocol can increase the lifetime of the sensor nodes' batteries by using their relaxation, which increases the lifetime of the sensor network. During the period of batteries' relaxation, the results that it can recover part of the batteries' power have been experimentally demonstrated, for example, intermittent operation of the alkaline battery can increase the life expectancy of about 28%. In addition, RELAX predicts the next hop through the path in the construction stage by using residual energy, node available buffer size and SNR. RELAX will split the sending information into equal sized segments, add error correcting codes, and then sends it to the multiple paths as well as increases the probability of an important part of the packet, thus it will not cause delay.

3.4 Other Methods

3.4.1 Network Coding

The traditional way of data transmission is to store and transmit, the intermediate nodes plays a role of transponder. Network coding is an information exchange technology that includes routing and coding. The most important part of this mechanism is that every node in the path can dispose the received information and then transmit it to the next hop. Network coding can encode the received data information of each node, which improves the utilization of the network link bandwidth.

In [13], the authors combined with XOR operation and operation of finite field method through 'butterfly network' model to research on the network flow in multicast networks. It describes the admissible code rate of multicast network and proves the use of network coding network multicast can achieve maximum flow minimum cut theorem under the maximum transmission capacity and thus be able to obtain better network throughput than routing multicast. At the same time, according to the situation of multi-source network, the authors adopted the use of convolutional codes of network coding which can decrease the time delay of data transmission in the network and balance the network load. But the nonlinear coding is very complex that need a further experiment and improvement. However, the method of combination of network coding and algebraic geometry, which brings a strong support for the future research.

Paper [14] pointed out that, network coding can improve reliability of lossy networks by reducing packet retransmission times. Although previous studies show that the network coding can improve network capacity, the gained reliability of the specific network is still unknown, therefore, this literature on network coding can improve the degree of reliability is quantified. Based on the model of the access point and tree topology of multicast, this paper makes a research on the comparison of ARQ and FEC and network coding's different reliable transmission mechanisms in a lossy channel and shows the numerical results and performance analysis.

First of all, in an access point broadcast data packets to a set of K receiver network model. When the size and the number of receivers to Θ (log K), the desired number of transmission data packets is significantly smaller than that of ARQ, but FEC experimental results are similar, which proves that compared with ARQ mechanism, network coding can indeed reduce the number of retransmission. Besides, based on tree topology of multicast model, this paper makes transmitted experiments of different reliable transmission mechanisms in end-to-end and interlinked. The results show that network coding can ensure the higher reliability of data transmission under the same number of retransmissions. We can predict from the literature research results that network coding can not only improve the reliability of the simple network, but also improve the reliability of the network that has diversity network topology with complex paths.

3.4.2 Cooperative Transmission

Cooperative communication can improve the reliability of the wireless terminal, and can save energy when multi-path transmits redundant information, at the same time, resist the signal decline in the multipath transmission process. There are two aspects of cooperative communication effect: on the one hand, it obtains communication gain through smaller hop number neighbor collaboration node or relay node; on the other

hand, an increase of the space complexity of the receiver can also bring the benefits of balance multiplexing technology.

The authors of [16] proposed a strategy that combined with cooperative communication technology and channel coding technology. This strategy chooses some relay node which are spatial dispersion, these nodes can decode packet data with higher successful rate and then transmit data collaboratively to other node. In addition, the outage probability of the information theory is analyzed, and the outage capacity can achieve the continuous performance gain compared with the direct transmission, and the diversity order is K + I (K is the number of relay nodes). Besides, the researchers developed a data transmission method based on cooperative transmission scheme and ACK. Experimental results show that the method can achieve a better balance between the system throughput and fairness, which improves the reliability of information transmission.

It is well known that MIMO technology and orthogonal space time block coding can improve the performance of the network system. The authors of [17] study the problem of reliable packet transmission in WSNs by using these two techniques. In order to satisfy the accomplishment of the biggest successful transmission rate (STR) with the given end-to-end energy consumption as well as greatly reduce the implementation complexity of the global optimization, this paper proposes a cross-layer optimization distributed square case jointed with channel coding and power control and routing planning of low complexity. The experimental results show that the proposed scheme can significantly reduce the symbol error rate (SER), which is obviously better than the traditional energy saving routing algorithm.

4 General Comparison

Some typical reliable transmission technologies of WSNs are introduced in above. Table 1 compares these technologies in terms of reliability measures (Metric), recover way, energy consumption, scalability and suitable applications. According to the

Table 1. Comparison of reliable transmission.

Name	Method	Metric	Reliability	Recover way	Energy consumption	Latency	Scalability	Layer
ESRT	Retransmission	Event reliability	High	End-to-End	Low	High	Middle	Transport layer
PSFQ	Retransmission	Packet reliability	Very high	Hop-by-Hop	Low	High	Low	Transport layer
AFECCC	Erasure code	Packet reliability	Very high	End-to-End	Low	High	Middle	Physical, data link layers
RDTS	Erasure code	Packet reliability	High	End-to-End	Low	Low	Low	Physical layer
ReInForM	Multipath	Packet reliability	Very high	Hop-by-Hop	High	High	Middle	Network layer

(*continued*)

Table 1. (*continued*)

Name	Method	Metric	Reliability	Recover way	Energy consumption	Latency	Scalability	Layer
MMSPEED	Multipath	Packet reliability	Very high	End-to-End	High	Low	High	Network layer
REER	Multipath +XOR	Packet reliability	High	End-to-End	Low	Low	Middle	Network layer
[8]	Node redundancy	Packet reliability	High	End-to-End	Low	Low	Middle	Network and MAC layer
RELAX	Multipath +FEC	Packet reliability	High	End-to-End	Low	Low	Middle	Network layer
[14]	Network coding	Packet reliability	Very high	Hop-by-Hop	High	Low	High	Physical layer
NCCC	Network coding	Packet reliability	Very high	End-to-End	Low	Low	Middle	Physical layer
[16]	MIMO + RBC	Packet reliability	Very high	End-to-End	Low	High	Middle	Physical layer
[17]	MIMO +OSTBC	Packet reliability	Very high	End-to-End	High	High	Middle	Physical, network layers
REECR	Cooperative relay + ARQ	Packet reliability	High	Hop-by-Hop	Low	High	High	Physical layer

feature analysis shown in Table 1, it is clear that event reliability tends to has lower energy consumption than packet reliability in various methods. Additionally, schemes using hop-by-hop seems to have higher scalability compared to the end-to-end approach, however, both ways can be used in different suitable applications.

5 Conclusions

This paper makes a summary of the reliability mechanisms in WSNs. We analyze the features and superiority of some typical protocols as well as make comparisons between these different methods. Both retransmission and redundancy techniques show their great features in the guarantee of transmission reliability. However, the hybrid way makes a deep comparison between the two techniques above, it summarizes the goodness and weakness in different area and analyze the best way to choose in various situations. Finally, new techniques such as network coding and cooperative transmission become hot topics, these unconventional techniques still do the good job in reliability increase and have a bright prospect in the future.

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