

Reliable Techniques for Data Transfer in Wireless Sensor Networks

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Abstract: *Reliable delivery of data is a key challenge in Wireless Sensor Networks (WSN). This paper discusses various challenges to achieve data reliability. Various data transport protocols that deliver data in both upstream and downstream directions are discussed in detail. Furthermore the existing data transport reliability protocols are analyzed based on various reliability levels. Techniques based on retransmission and redundancies are discussed. Retransmission techniques seem to be efficient but leads to overhead. Redundancy techniques like erasure code, Reed Solomon codes and route fix seems to be the best alternative in a resource constrained WSN. Finally it has been stated that the right combination of retransmission and redundancy techniques helps to achieve high reliability. On the basis of the analysis, few research challenges to achieve reliability are pointed out.*

Keywords: Reliability, Upstream, Downstream, Transport protocols, Redundancy and Retransmission.

1. Introduction

A Wireless Sensor Network(WSN) consists of a large number of nodes which are deployed in a large region and used for a variety of applications including area monitoring, industrial and process control, object tracking, healthcare monitoring, military surveillance and so on. A sensor node consists of a sensing unit, processing unit, transceiver unit and a power unit. Depending on the application, it may also include a location finding system and a mobilizer. Sensors typically have five basic software systems. They are Operating System (OS) microcode, sensor drivers, communication processors, communication drivers and data processing mini-apps [1]. A number of sensors are distributed in a given region whose task is to sense the data and send them to sink node. The aggregated data are then sent to the end user to accomplish the given task. The main requirement of a wireless sensor networks are Reliability, Scalability, Responsiveness and Power Efficiency [2]. The data sensed by the nodes should be reliably delivered to the end user which is a cumbersome task. For certain applications, certain loss of data is acceptable. But for some critical applications like military surveillance or in case of object tracking, loss of data is unacceptable. Therefore reliability is a major issue in sensor networks.

2. Reliability issues in Wireless Sensor Networks

Reliability could be defined as “The ability of the network to ensure data transmission in a state of continuous change of network structure.”[3] Reliable data delivery is restricted mainly due to the inherent nature of wireless communication system. Packet loss could occur due to transmission error, congestion, electromagnetic - radio frequency interference (EMI/RFI) or due to energy depletion

problem. All the sensor nodes send their sensed data towards the sink node. This may lead to flooding which causes network congestion. Moreover sensor node has limited battery power and so to deliver data it must use the best routing strategy to reduce the number of hops as it needs to conserve energy [4].

Reliability could be evaluated based on packet arrival probability and energy efficiency is evaluated in terms of energy consumed in successful delivery of a packet. Successful data delivery also depends on optimized path since multihop wireless sensor networks are employed [5, 6].

Reliability can be classified into the following types:

Based on reliability level

a) Packet reliability:

- It requires the entire packet to be delivered from the source to the destination.
- Needs acknowledgment from the destination to the source.
- Requires lot of energy resources to re-send entire packet from source to destination.

b) Event reliability

- Only the sensed event needs to be sent to the base station based on the query.
- Does not need acknowledgment.
- Even loss of data does not give much impact.
- No unnecessary data retransmission.

Based on reliability direction

a) Upstream Reliability: It refers to the communication between sensor node and sink node. The transmission is usually

unicast in nature. Many protocols provide upstream reliability.

b) Downstream Reliability: It refers to the communication between sink and the sensor node. The transmission is usually broadcast in nature.

3. Overview of Data Transport Reliability in Sensor Networks

The role of transport layer is to deliver reliable data in a timely manner with no congestion and no loss of data with limited energy consumption. Transport layer protocols namely Traditional TCP and UDP are not suitable for WSN. TCP uses end – end transmission control mechanism and the congestion mechanism used is also not suitable for WSN. UDP does not provide acknowledgment schemes. UDP is connectionless and does not provide flow and congestion control [7]. However transport protocols can be made suitable for WSN by taking into account the following design considerations:

1. WSN needs a mechanism for packet loss recovery such as acknowledgement.
2. The initial connection establishment procedure should be simplified. The three way handshake process will be a big overhead to transfer small volume of sensed data.
3. The protocols should implement proper congestion avoidance schemes.
4. The protocols should guarantee fairness for all sensor nodes.
5. The transport control protocol should provide cross layer optimization.

Data transmission can be either end-to- end or on a hop-by- hop basis. In case of end- to-end transmission, the source and the destination are responsible for the delivery of the entire packet. In case of data loss, the source has to transmit the entire packet. This leads to more energy consumption which is not feasible for wireless sensor networks. Hop-by- hop data transmission requires the neighbouring nodes to transmit the data. So in case of data loss, retransmission can be performed easily with less energy consumption. Hop-by-hop requires local buffer and is more effective in case of multihop WSN. Therefore hop-by-hop is more suitable for resource constrained WSN.

Reliability is achieved either by retransmission or redundancy. In retransmission mechanisms, the source node after sending the data requires an acknowledgment of its data packet from the receiver to ensure reliability. Redundancy mechanisms on the other hand send multiple copies of the same message to its receivers.

3.1 Reliability through Re-transmissions

Various acknowledgment schemes are used in retransmission mechanisms. Few among them are:

Explicit acknowledgment (eACK): The receiver node sends a special control message to the source after the successful arrival of the packet. It results in high transmission overhead as acknowledgment is needed for every sent packet.

Negative acknowledgment (NACK): The receiver notifies the sender about the missing packets.

3.1.3 Implicit acknowledgment (iACK): It makes use of the broadcast nature of the wireless channel. The sender after sending the data listens to the channel and makes sure that the data packet is sent by the next hop to its neighbour which is a sign of acknowledgment.

3.1.4 Selective acknowledgment (sACK): Only the lost packet in the entire message is resent.

3.2 Transport Control Protocols using Retransmission mechanisms

A number of protocols are used for reliable transport of data. Some provide reliability in upstream direction and some in downstream direction. Only very few protocols provide reliability in both directions. Some protocols concentrate only on reliability, while some protocols rely both on reliability and congestion mechanism. To provide reliable data flow, it is essential that the data path is free from congestion. All the protocols use retransmission based data recovery in case of packet loss. Few existing data transport protocols which are widely used by main applications are: GARUDA, ESRT, RMST, PSFQ, ART, PORT and DST[8,9].

3.2.1 PSFQ

Pump Slowly Fetch Quickly (PSFQ) is a downstream reliability protocol[9]. This protocol slowly injects packets into the network (pump operation). In case of data loss, the protocol performs aggressive hop-by-hop recovery. It uses NACK scheme. This protocol does not provide congestion mechanism and does not handle single packet loss.

3.2.2 ESRT

Event-to-Sink Reliable Transport protocol is an upstream reliability protocol which is used for transmitting event information rather than data packet [17]. It includes congestion notification bit. The traffic of the source node are periodically monitored during reporting frequency. This self configuring nature makes it to adapt to dynamic environment. It does not use NACK/ACK scheme. NACK leads to overhead and ultimately energy expenditure. This protocol also works even in case of multiple event detection using eventid.

3.2.3 DST

Delay Sensitive Transport is an extended version of ESRT [17]. DST aims to achieve event detection reliability at the sink. It introduces a Time Critical Event First (TCEF) scheduling policy. In case of TCEF, the data packet with minimum deadline is given first priority for retransmission. DST works best for single event and in case of random multiple event, the case becomes a bit complicated.

3.2.3 GARUDA

It is a downstream reliability protocol which uses hop-by-hop recovery mechanism [8]. It uses NACK schemes and contains no congestion control mechanism. It uses WFP (Wait for First Packet) pulse transmission mechanism.

3.2.4 ART

Asymmetric Reliable Transport Protocol (ART) is based on event and query reliability [17]. It is the first bidirectional transport protocol that implements congestion control. It consists of a series of nodes called essential nodes that cover the whole sensing area. Few nodes called non-essential nodes are involved in transmission and congestion control.

3.2.5 RMST

Reliable Multi Segment Transport Protocol (RMST) is a selective NACK based protocol [7]. It is an upstream reliability protocol. It is built on top of directed diffusion which discovers path from sensors to sink. It uses timer to detect packet loss and is not suitable for event detection. It does not include congestion control and has no energy conservation schemes.

3.2.6 PORT

Price Oriented Reliable Transport Protocol (PORT) provides event reliability with minimum energy consumption [9]. It adjusts reporting frequency of source nodes and performs better than ESRT. It provides energy efficient congestion control mechanisms. It follows end-to-end communication mechanism. PORT requires the sink to regulate the data flow. But there are no packet recovery schemes. It is an upstream reliability protocol.

3.3 Retransmission through Redundancy

Retransmission based reliability mechanisms require the transmission of the entire packet from the source to the destination in case of a packet loss. Moreover acknowledgment requires overhead. Another way of achieving reliability is to use the concept of redundancy where multiple copies of the same packet are transmitted which is very helpful in case of packet loss. Forward Error Correction (FEC) is used to correct only the lost or corrupted bits. This saves considerable amount of energy in resource constrained WSN. FEC technique is used only in the physical layer. Erasure code which is a class of FEC technique is used for error correction and detection in higher layers as the exact position of the lost or corrupted bits are known at these higher layers [12, 13].

3.3.1 Erasure Codes

The sender divides the data packet into n fragments and k redundant bits are added so that the total number of bits sent becomes $(n+k)$. The receiver receives the data and decodes them when the received data is greater than or equal to $(n+k)$. Erasure coding can be performed in a hop-by-hop or end-to-end basis. In case of hop-by-hop mechanism, the encoding/decoding is performed at the intermediate nodes whereas end-to-end performs the encoding and decoding operations only at the source and sink.

3.3.2 Reed Solomon Codes

These are a class of erasure codes which can be used to detect and correct random errors. They are very much suitable for correcting burst errors. They are widely used in electronic consumer goods, telecommunications and in wireless technologies. These systematic codes are nowadays widely used as the time to decode takes less time thereby increasing reliability at the same time reducing the node's processing or computational speed. But there is always a risk of high network cost when such systematic codes are used.

3.3.3 RDTS

RDTS stands for Reliable erasure coding based data transfer scheme. Here erasure coding is performed at each hop rather than at the source and sink. RDTS applies partial coding mechanism at each hop. Partial coding mechanism reduces overhead as the encoding / decoding is performed on each hop only when there is a packet loss. RDTS is very energy efficient. It is an upstream reliability protocol.

3.3.4 FBcast

It is a downstream reliability broadcasting protocol based on FEC. FBcast uses fountain codes which are a class of erasure codes. The technique is to send a block of encoded data to its neighbours which can be further rebroadcasted to its neighbours and so on. FBcast is suitable for single hop WSN. In case of multi hop WSN, an extended version of FBcast along with repeaters is used.

3.3.5 DTSN

Distributed Transport for Sensor Networks is an energy efficient transport protocol that provides upstream data transmission in a reliable way. It provides full or differential reliability levels. When all the packets are necessary to be delivered to the sink, end-to-end technique is used. Otherwise, FEC mechanism is added to DTSN. Full reliability mode uses ACK/NACK recovery schemes. Enhancement Flow is added with FEC to transfer data in blocks which results in high reliability. It also needs cache management mechanisms during this bulk transfer. This protocol may not be suitable when there are a number of hops between the source and the sink.

Table1. Comparison of Retransmission based Transport protocols

<i>Protocols</i>	<i>Reliability Directions</i>	<i>Reliability Level</i>	<i>Loss Recovery Mechanism</i>	<i>Type of Ack</i>	<i>Congestion Mechanisms</i>	<i>Energy Efficiency</i>
GARUDA	Downstream	Packet	Hop-By-Hop	NACK	No	No
ESRT	Upstream	Event	End-To-End	-	Yes	Yes
RMST	Upstream	Packet	Hop-By-Hop	NACK	No	Yes
PSFQ	Downstream	Packet	Hop-By-Hop	NACK	No	No
ART	Both	Event	End-To-End	-	Yes	Yes
PORT	Upstream	Event	Hop-By-Hop	-	Yes	Yes
DST	Upstream	Event	End-To-End	-	No	Yes

Table2. Comparison of various Redundancy Schemes

<i>Coding Scheme</i>	<i>Reliability Directions</i>	<i>Reliability Level</i>	<i>Loss Recovery Mechanism</i>
Erasure Code	Upstream	Packet	End-To-End
Reed Solomon Code	Upstream	Packet	End-To-End
RDS	Upstream	Packet	Hop-By-Hop
DTSN	Upstream	Packet	End-To-End
FBcast	Downstream	Packet	Hop-By-Hop

4. Proposed Method

Reliable delivery depends on probability of success and the ratio of packets sent to the packets received. Therefore for a successful delivery of data, various combinations of retransmission, redundancy techniques are to be followed. As suggested by author [4], cost and overhead need to be considered for every option that is followed. By increasing the no of parity bits, reliability is increased and the probability of packet loss is decreased. But there is a considerable increase in computation cost and overhead. Moreover erasure codes and other systematic codes needs to be modified according to the current trends of sensor networks. Retransmission and use of alternative route options are used only on-demand thereby reducing the cost.

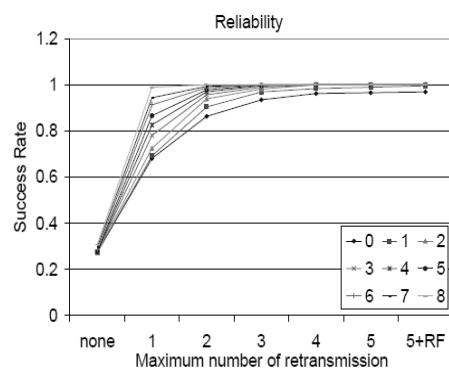


Figure1. Success rate of End-to-end transmissions

Author [16] suggests an In-middle recovery mechanism that seems to be better than hop-by-hop and end-to-end mechanisms. In this mechanism, a packet loss is detected after few hops and a new packet is generated which travels

upto few more hops. This procedure is repeated until the packet reaches the destination. The node that generates the packet is called the reproducer and the generated packets are called seeds. The path taken by the seeds are disjoint. Therefore the problem of load balancing, congestion and link quality interferences are alleviated. This routing procedure is called proliferation routing which is based on EPX routing metric.

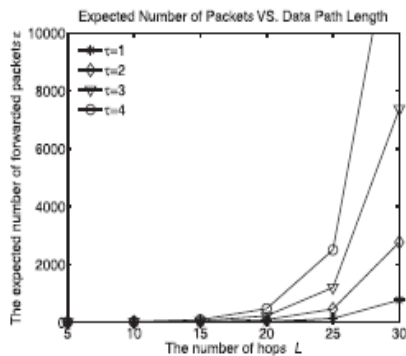


Figure 2. Success rate using in-middle recovery with EPX metric

Therefore it has been proven that 99% of reliability is achieved by right combination of retransmission / redundancy techniques along with a proper routing strategy.

5. Conclusion and Future Work

Wireless Sensor Networks are mainly used in monitoring and control. Moreover WSN are mainly used for specific application. So reliability is a very important requirement of WSN. It is achieved either by hop-by-hop or end-to-end mechanism. Retransmission seems to be more suitable for hop-by-hop packet delivery scheme especially when hop count is high. It is more suitable to provide event reliability. But hop-by-hop requires more buffer space and so an efficient buffer management scheme is just sufficient for hop-by-hop mechanism. In case of end-to-end mechanism the acknowledgment schemes requires more overhead. Therefore in such situations, redundancy techniques can be used. But they are not suitable in case of noisy environment and when there is a high probability of packet loss. In such a case alternate route fix is the best strategy. In-middle recovery can be used when either option does not work out.

Congestion control plays an important role in minimizing packet loss which enhances reliability. Moreover nodes should suppress retransmission in case of congestion. Congestion detection and avoidance mechanism should be implemented which enhance reliability. Accurate event detection and defining priorities will help to improve reliability levels. In-node data processing techniques should be enhanced so that the sink can control data flow and check for reliability.

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