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Reliability in MAC Protocols for Wireless Sensor Networks: A Survey

Nicholas N. Karekwaivanane[1], Wilson Bakasa[2], Kudakwashe Zvarevashe[3]

M Tech Student, Dept of CSE, Jawaharlal Nehru Technological University, Hyderabad, India[1]

M Tech Student, Dept of CSE, Jawaharlal Nehru Technological University, Hyderabad, India [2]

M Tech Student, Dept of CSE, Jawaharlal Nehru Technological University, Hyderabad, India [3]

ABSTRACT: The field of wireless sensor networks has received widespread acceptance because of the ease deployment of nodes, no prior installation of infrastructure before deployment and low cost of operation. This has caused research in WSN to diversify and not only focus on energy conservation but to also look at ways to enhance the data performance of the network. QoS parameters such as reliability, loss, latency and bandwidth are now at the center stage of research. This paper focused on reliability in wireless sensor networks. A survey is performed on existing MAC protocols that provide reliability and they shall be classified according to the nature of the reliability they provide. There are protocols that provide node to node reliability and those that provide end to end reliability. We shall then analyze challenges associated with these existing mechanisms then propose future research directions.

KEYWORDS: Wireless Sensor Network; Reliability; MAC Protocols, QoS, Survey

I. INTRODUCTION

Therehas been a marked increase in the number of applications for wireless sensor networks in recent years. This can be attributed to factors such as the low cost, no upfront setup in the environment prior to deployment, the ability to be deployed in adhoc fashion and still manage to communicate without challenges amongst many others. Initial research was targeted at maximizing the network lifetime whilst trading off factors such as the bandwidth, latency, reliability and loss.

New application are now making demands that have shifted research to other areas such as the data transport performance. Reliability is one such factor and we are going to discuss in this paper. The MAC layer is the most important layer in the protocol stack for WSNs because most control mechanisms are implemented in this layer. In applications where strict data delivery must be enforced mechanisms must be put in place to ensure that data is delivered in a reliable manner. This paper is going to focus on MAC layer protocols that provide reliability.

The remainder of this article is structured as follows: Reliability and classification of reliable protocols are discussed in section II. Section III discusses approaches taken by various MAC protocols to achieve reliability. In section IV we highlight challenges faced by existing protocols, identify potential research directions and conclude.

II. RELIABILITY IN WSN

Reliability is the ability of the WSN to guarantee that the data is always delivered. The time the data is delivered is not a major concern but the data must always reach the intended recipient. Reliability in WSN is often dealt with in upper layers such as routing but we can also deal with it in the MAC layer by reducing packet loss [8].The following factors are the reasons why mechanisms to provide reliability are in place:

- Constrained resources
- Radio frequency interference
- Synchronization

The MAC layer has several methods to enforce reliability and the list below gives possible methods that can be used.

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- Improve the reliability of individual components
- Increase the number of paths between the source and destination
- Decrease the number of intermediate links
- Improve channel quality and remove link errors

Reliable MAC protocols can be said to provide two kinds of reliability: node to node reliability and source to destination reliability.

Node to node reliability – in this circumstance the reliability is small scale and it is being enforced between two adjacent nodes. The protocol can increase the reliability or guarantee the delivery.

End to end reliability –the reliability is enforced at a large scale and it is from the source to the destination not only at two adjacent nodes. The protocol can increase the reliability or guarantee the delivery.

III. RELIABLE MAC PROTOCOLS

In this section we are going to analyse a number of protocols and explain how they provide reliability.

1. Rainbow: Reliable Data Collection MAC for WSN

This increases the Hop to Hop reliability in a WSN that has a tree topology [1]. The MAC layer in Rainbow enhances the reliability by reducing the radio frequency (RF) interference in the wireless medium. To achieve this it uses a local TDMA scheme coupled with a frequency-hopping spread spectrum (FHSS). The combination of TDMA and FHSS control channel access.

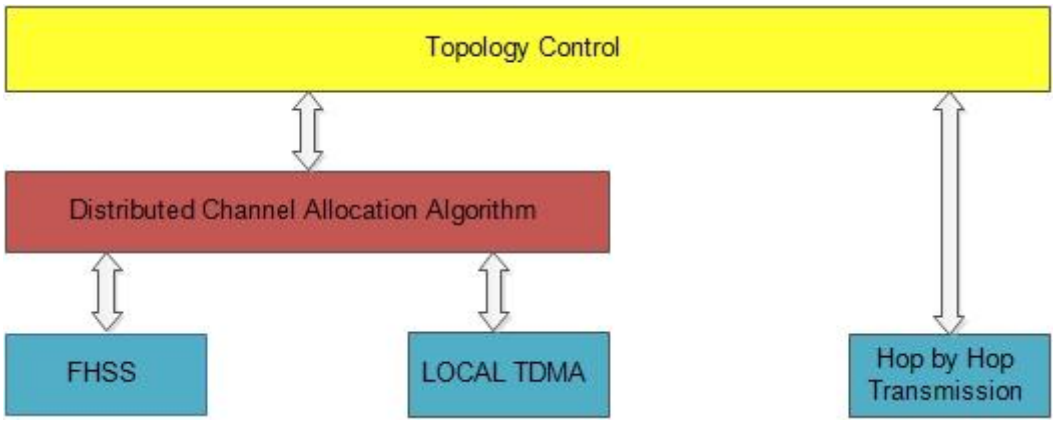

Figure 1: Architecture of Rainbow (1)

The FHSS is responsible for reducing collision, increasing throughput and preventing interference. Whenever a collision occurs the node uses a technique called temporal diversity to change the frequency to ensure that the collision does not reoccur An Algorithm called PUNCH is used to prevent collisions by allocating exclusive time frequency channels to each node.

2. On-Demand Reliable MAC (RMAC)

This is a CSMA/CA bases MAC protocol that increases the node to node reliability [2]. It works in an error prone medium. To enforce reliability it uses implicit and explicit ACKs.
When a node wishes to transmit a packet it first waits for a random back-off to check if the channel is in use. If the channel is busy it waits again until the channel becomes free. The back-off waiting time is obtained using the formula:

$$RB=[0.2^{cw} * slotTime] \quad (2)$$

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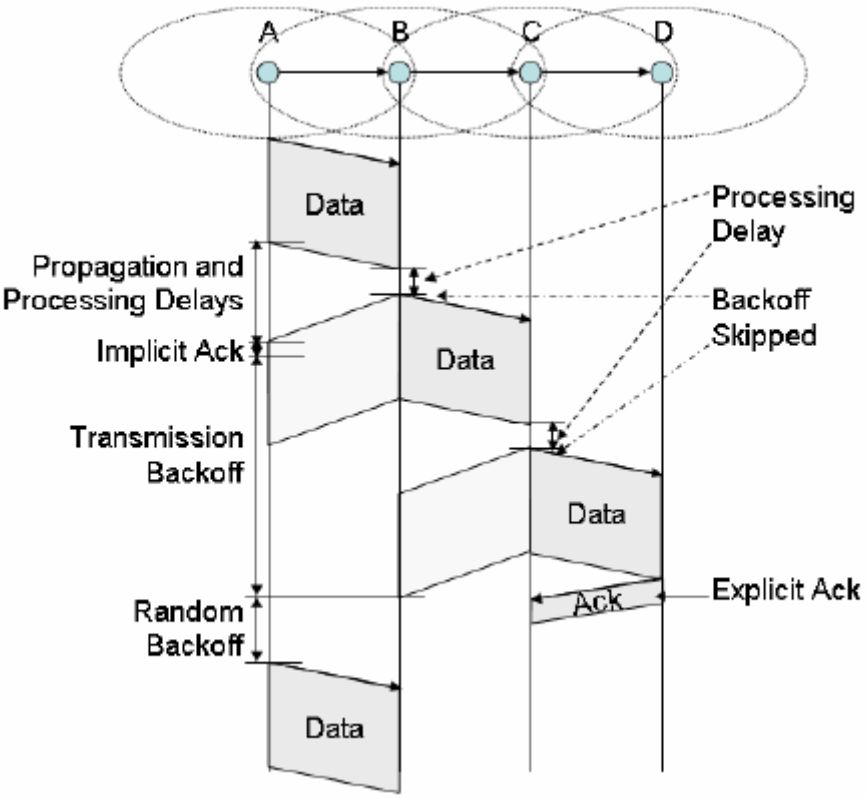

Figure 2: RMAC Operation (2)

On transmission if the message is at an intermediate node the node does not send an ACK to the previous node. The previous node will receive an implicit ACK when it overhears the node forwarding the message. If it is the destination node it will send an explicit ACK. In the event that an implicit or explicit ACK is not received retransmission will occur. The number of retransmissions is proportional to the channel error rate. The formula for calculating retransmissions is:

$$\text{Retransmission Attempts} = T_{X\text{-}ATTEMPS} + (1/(1 - P_e)) \qquad (2)$$

Where $T_{X\text{-}ATTEMPS}$ – maximum number of retransmissions
P_e- Packet error rate

3. Energy Efficient On-Demand Reliable MAC (E2RMAC)

This is an enhancement of RMAC that introduces energy efficiency by using two radios a wake up radio and a transmission radio [6]. It also increases the node to node reliability. Reliability in this protocol is also enforced by implicit and explicit ACKs but the mechanism differs. When an intermediate node receives a message it does not perform back-off before it accesses the channel it automatically sends a wake up signal to the next node on the wakeup radio and when the node wakes up it begins transmission. The wakeup signal is an implicit ACK to the sender.

When a sender fails to receive an ACK it retransmits the packet after waiting for a back-off period. If the message has reached the final destination the receiving nodes sends a wakeup tone to the sending node as an explicit ACK. A mechanism is put in place to prevent collisions between two adjacent nodes that have communicated recently. When a sender receives an ACK, explicit or implicit it does not transmit for a period that is equal to the time it takes to transmit a message and receive an ACK. During this time the node will not accept wake up signals. Since the wireless medium

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is a broadcast medium, nodes around two communicating nodes overhear the communication between the two nodes setting up communication they sleep for a period that allows communication between these nodes and if they want to transmit they wake up after this period.

4. Adaptive Power Transmission Control (ATPC)
This is an algorithm that uses feedback to adjust the power of the signal in order to control the quality of the link [3]. This algorithm increases the node to node reliability. The algorithm considers the spatial and temporal effects of the environment on the link. Each node has a model for each neighbour that it uses to control the transmission power based on the link quality. Feedback history between the two nodes is used to establish the model. This history is used to gauge the transmission power required to ensure better link quality and reliability.

The spatial effect of the environment is used to find the minimum power to use to send data maintaining a quality link using constant factors of that environment such as terrain and the distance between the nodes. The temporal effects are the sudden changes in the environment that may or may not be permanent but require the transmission power to be adjusted to maintain a quality link such as weather or the appearance of an obstruction between the two nodes. Any change in the transmission power is a direct response to changes in the environment. ATPC not only enhances the reliability of the network but also improves the lifetime of the network because energy is optimally used by the sensor during transmission. ATPC uses received signal strength indicator (RSSI) and link quality indicator (LQI). RSSI is an averaged measurement of the signal strength. LQI is the chip error rate. A relationship between link quality and RSSI/LQI is studied to establish an effective power control mechanism.

5. QoS MAC
This is a TDMA based MAC protocol that increases the node to node reliability [4]. The nodes are arranged in a tree topology with the root being the sink node. All the nodes in the tree are synchronized. A time period called an epoch is the base time unit for this protocol. The epoch is then divided into slots that can be equally divided amongst the available nodes (k*n slots). Each slot is large enough to transmit data and receive an ACK. The nodes are not randomly deployed such that slot assignment is preconfigured before the deployment to enforce synchronization. No collisions will occur in this setup.

A node is assigned k successive slots in each epoch. When a node's slot arrives it must always send a message in its first transmission slot for that epoch. That message can contain either data meant for another node or a control message if it has no data to send. A packet will be retransmitted in the node's next slot in the event that the node has not received an ACK.

6. Delay-aware Robust Forwarding for Energy Constrained WSN (DWARF)
DWARF increases the end to end reliability. It uses unicast based partial flooding coupled with a greedy node selection strategy to forward the data towards the sink node [5]. The nodes in DWARF are arranged in a graph structure with each node having parents, peers and children. Node selection in DWARF is determined by the wake up time and the relative position with respect to the sink node.

In the event that a node wants to transmit an alarm message it has to forward the message k times redundantly to different nodes to ensure that the message is reliably sent. The nodes that this message is sent to are selected form the list of parents and the list of peers of the node. The parent list is the first to be chosen from and if it is exhausted before k is reached nodes will then be chosen from the neighbour list. In each list the node that is chosen is the next node to wake-up and it is removed from the list after a message has been transmitted to it. If a message is lost during transmission for any reason the packet is retransmitted to and during this retransmission it is sent to a new destination to ensure that the message is not delayed because of one node. Each node also sends a status message to its neighbouring nodes so that they know that it is alive. This status message also contains a list of the nodes that it knows to be alive. The status message is propagated from the last nodes in the network towards the sink. Each node adds the nodes it knows to this list and by the time it reaches the sink a list of all the nodes known to be existing is obtained by the sink node giving it a picture of the network state.

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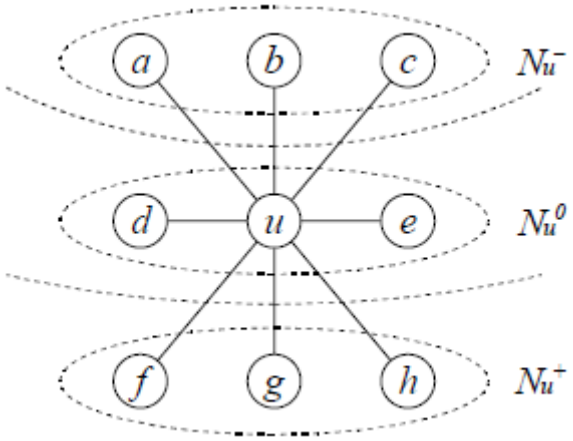

Figure 3: Arrangement of Nodes in DWARF (5)

7. Multipath Multi-SPEED Protocol (MMSPEED)

This enforces a probabilistic end to end delivery guarantee [7]. It provides a differentiated reliability guarantee for each transmission flow.

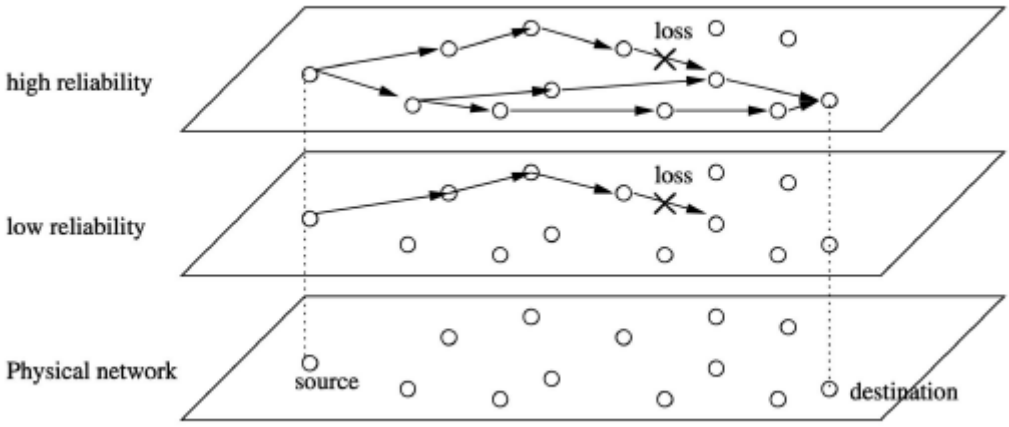

Figure 3: MMSPEED Reliability Provisioning (7)

A packet is sent on multiple paths to ensure that it reaches the destination on a lossy and erroneous channel. MMSPEED increases the number of paths proportionally to the level of reliability required. It uses two techniques to achieve this

- Dynamic compensation
- Multipath forwarding

A node maintains a link quality metric $e_{ij}$to each neighbour. This metric is used to calculate the end to end reachability.

$$RP_{ij}^{d} = (1-e_{ij})\,(1-e_{ij})^{[distjd/distij\ ]}$$

From this reachability we can calculate the number of forwarding paths using

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$$TRP = 1 - (1 – TRP)(1 - RP_{ij}^{d})$$

IV. CONCLUSION AND FUTURE WORK

A lot of research has been carried out on improving the data and transport performance of data in WSN. In this paper we have analyzed existing MAC protocols and the measures they have put in place to increase reliability. The majority of the protocols deal with reliability on a node to node basis. For the protocols that deal with reliability on an end to end basis DWARF increases the end to end reliability and MMPEED provides probabilistic reliability guarantees. There is still a lot of research that needs to be carried out on end to end reliability because with it we can get source to destination delivery guarantee.

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BIOGRAPHY

Nicholas N. Karekwaivanane born in 1985, received his B Tech degree in Computer Science at HIT, Zimbabwe in 2010. He is currently doing M Tech CS final year at JNTUH, India. He is a HIT staff development research fellow. His research interests are in the area of computer networks, information security, cloud computing and adhoc and sensor networks.

Wilson Bakasa born in 1983, received his BSc degree in Computer Science at Bindura University, Zimbabwe in 2008. He is currently doing M Tech CS final year at JNTUH, India. He is a HIT staff development research fellow. His research interests are in the area of Information security, wireless and sensor networks and cloud computing.

.**KudakwasheZvarevashe** born in 1986, received his BSc degree in Information Systems at MSU, Zimbabwe in 2010. He is currently doing M Tech IT final year at JNTUH, India. He is a HIT staff development research fellow. His research interests are in the area of big data, information security, cloud computing and web services