RLL-MAC: Reliable and Low Latency MAC for Event Critical Applications in Wireless Sensor Networks

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Summary
Wireless Sensor Networks are appealing to researchers due to their wide range of applications like target detection and tracking, surveillance and localization. Energy management is a critical issue to prolong the network lifetime in senor networks. Clustering is an effective technique to improve energy efficiency and network lifetime. In addition to energy efficiency, Latency and reliability are prime concerns in sensor networks. We propose a new protocol, RLL-MAC (Reliable and Low Latency Medium Access Control) for event critical applications that provides a reliability approach in election of cluster head and a dynamic wake up scheme to reduce the latency.

Key Words:
Wireless Sensor Network, Medium Access Control, Cluster head, Reliability, Low Latency

1. Introduction

Wireless Sensor Networks [1] are gaining popularity across a diverse research community in the current decade due to their potential usage in commercial, defense and scientific applications. Improvements in hardware technology have resulted in low–cost sensor nodes, which composes of a single chip with embedded memory, processor and transceiver. Low power capabilities have lead to limited coverage and communication range for sensor nodes. Sensor nodes can sense the environment change and exchange data with its neighbors. Several sensor prototypes such as UC-Berkley's Smart Dust and Mica Motes [2] have been developed. Wireless Sensor Networks are different from existing wireless communication networks in the following aspects;
-Traffic rate is very low.
-Sensor nodes are battery operated.
-Sensor nodes are generally stationary.
-Sensor nodes in the network coordinate with each other to implement a certain function.
Due to these differences, existing MAC protocols such as IEEE 802.11[3] are not suitable for Wireless Sensor Networks. Medium Access Control (MAC) protocols coordinate the times where a number of nodes access a shared communication medium. The most important requirement is energy efficiency and specific sources of energy wastage in MAC are: Overhearing, Collisions, Overhead and Idle Listening. MAC protocols can be roughly classified into the following classes [4]: Fixed Assignment, Demand Assignment and Random Access Protocols. TDMA (Time Division Multiple Access), FDMA (Frequency Division Multiple Access), CDMA (Code Division Multiple Access) and SDMA (Space Division Multiple Access) are the typical protocols in fixed assignment class. In Fixed assignment [5] the available resources are divided to the nodes such that each node can use its resources exclusively without risk of collisions. The Demand Assignment class [6] is subdivided into Centralized and Distributed.HIPERLAN/2, DQRUMA, MASCARA, Polling Schemes comes under centralized where the nodes send out requests for Bandwidth to a central node. EEE 802.4 Token Bus is a Distributed, where the right to initiate transmissions is tied to reception of a special token frame. ALOHA or Slotted ALOHA developed at University of Hawaii is one of the first and still very important random access protocol. In this random class, i.e., CSMA Protocols where first the node is required to listen to medium before transmitting. The CSMA Protocols is basis of several widely used standards including IEEE 802.11.

1.1 MAC Protocols for WSN:

The first and foremost is the need to conserve energy. Other typical performance figures like fairness, throughput, scalability, robustness and latency play a minor role in Wireless Sensor Networks. MAC Problems are influenced by a number of attributes and trade off's like: Collision Avoidance, Energy Efficiency, Scalability and Adaptivity, Channel Utilization, Latency, Throughput and Fairness.

Collision Avoidance: Collisions incurs receive costs at destination node and Transmit costs at source. Fixed assignment or Demand assignment can avoid collisions or by collision avoidance/hidden terminal methods in CSMA.

Energy Efficiency: As it is difficult to change or recharge batteries for the sensor nodes, prolonging the lifetime is very critical. The MAC layer controls the radio activities and saves the energy.

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Scalability and Adaptivity: These accommodate changes in network size, density and topology. As the wireless sensor networks are deployed in an adhoc manner, new nodes may join or some may die. A good MAC protocol should support these changes effectively.

Channel Utilization: Bandwidth utilization or channel capacity specifies how efficiently the channel is utilized, which is a secondary goal.

Latency: Wireless Sensor Networks are used for surveillance or monitoring applications where the sensed data detected should be transmitted with less delay

Throughput: This specifies the amount of data successfully transmitted from the source to the sink. Factors like collision, channel utilization, latency and overhead affect the throughput.

Fairness: Fairness is not as important as the nodes in Wireless Sensor Network don't represent individuals competing for bandwidth.

1.2 Energy problems in MAC layer:

The transceiver will be in one of the four states: Transmitting, Receiving, Idling or Sleeping. Transmitting is very costly where as receive costs are same order of magnitude as transmit. Idling is significantly cheaper whereas sleeping costs are almost nothing.

Collision: Collision is a problem in random based but can be avoided in fixed and demand assignment protocols.

Idle listening: This state takes place when node is listening to channel to receive data. Switching off the transceiver is a solution to idle listening.

Overhearing: Wireless medium is a broadcast medium and all the neighbors in receive state receive the packet. Overhearing avoidance can save significant energy.

Control packet: RTS and CTS packets or request packets consumes energy. These control packets reduce the good put.

In our paper we proposed a novel approach of selecting cluster head in a reliable fashion and a wakeup scheme to reduce latency.

The rest of the paper is organized as follows. In section 2, the related work about various types of TDMA based MAC protocols and On Demand wakeup schemes. The proposed scheme to achieve reliability and low latency is presented in section 3.The simulation results are presented in section 4. Finally, the conclusion is given is section 5.

2. Related Work

In sensor networks, nodes are in idle state for most of the time when no event happens. This leads to significant waste of energy, since the radio is the major energy consumer. The preferable approach is to make nodes switch off and make active when needed. In this section, a wide range of TDMA based MAC Protocols and wakeup on demand schemes are discussed. There exists several scheduled i.e. fixed assignment protocols such as, Traffic Adaptive Medium Access Protocol (TRAMA) is Traffic adaptive distributed election scheme selects receivers based on schedules announced by transmitters. TRAMA [7] consists of three components: Neighbor Protocol (NP), Schedule Exchange Protocol (SEP) and Adaptive Election Algorithm (AEA). The channel consists of two intervals: Random and Schedule, random is slotted and used for signaling purpose where as schedule is used for data transmission. In TRAMA Sensor nodes may not operate optimally when inconsistent state develops, which can lead to decreased performance, Utilizes resources more intensely than many other protocols and transmission slots are set to be seven times longer than random access period.

Data Gathering MAC [8] employs a staggered active/sleep schedule and enables continuous data forwarding on the mutihop path. The data delivery paths from sources to sink are in tree structure, a data-gathering tree. In DMAC, nodes doesn't remain active for the next slot, Slot –by –slot mechanism costs overhead of more data flag bit and Collision avoidance methods are not utilized.

LEEMAC [9] employs single slot renewal mechanism in which initially length field, showing filled buffer length is transmitted along the path on the tree. In LEEMAC**,** Collision chances may increase incase of any packet loss and sleep delay is not cleared completely

Distributed Energy Aware MAC is based on critical observation, mainly on relative energy levels over a period of time. In addition criticality is a function of location of nodes within dynamically changing Query routing trees. In DE-MAC [10], Current leader transmits its energy level, which leads to unnecessary leader election and nodes has to keep radio awake in the slots assigned to neighbors

In Self-Organizing MAC for Sensor Networks First pass is performed which combines neighbor discovery phase where nodes discover their neighbors and Channel assignment phase, which establishes transmission and reception schedules. SMACS [11] wastes the time slots and frequent switching can cause energy loss.

Energy –Efficient MAC Protocol for Sensor Networks is a TDMA based MAC Scheme. Time is divided into frames and each frame is divided into slots and each slot contains three sections: Communication Request (CR), Traffic Control (TC) and Data Section. In EMACS [12] **t**raffic Control section is to be deployed to make wake-up calls.

Pattern MAC [13] adjusts duty cycle based on traffic conditions. To accomplish sensor nodes, sleep and awake times are shared for the next frame through a pattern sharing procedure. In PMAC, Some nodes may not receive the updated patterns and functionality of algorithm depends on traffic intensity.

Wakeup schemes are categorized as synchronous or asynchronous schemes. STEM [14] (Sparse Topology and Energy Management) uses two radios; one function as wakeup radio and the other is used for data transmissions. PTW [15] (Pipelined Tone Wakeup) uses wakeup tone channel in addition to regular data channel

3. RLL-MAC (Reliable and Low Latency Medium Access Control):

RLL-MAC is centralized MAC protocol based on TDMA. Initially when all nodes have the same energy considering homogenous environment, TDMA schedule is implemented where all the nodes wakeup in their transmit schedule even though they don't have data. Unlike several protocols we treat all nodes equally, but over a period of time based on observation of sensed event, we treat differently. TDMA frame is constructed by the cluster head and broadcasts the frame to all the nodes. This specifies when a node can transmit or receive the packet and dictates when the nodes go to sleep node.

The main advantages of RLLMAC are the following:

-Packet loss due to collisions is absent by using a TDMA protocol.

-No contention mechanism is required, since the slots are preassigned to each node.

-Increases the network lifetime by making the nodes sleep for a long duration.

-Selecting the cluster head is based on reliability.

-Low Latency is achieved.

Different phases in RLLMAC:

-Cluster head election.

-Cluster Formation.

-Data collection and Transmission

3.1 Cluster Head Election

3.1. a Cluster head Election Phase

LEACH [16] is a clustering based protocol that applies randomized rotation of cluster heads to evenly distribute the energy among the sensor nodes in the network. The Cluster Head elections take place periodically to distribute the cluster head responsibility over the cluster. In the cluster head election phase the present cluster head initiates the election process and elects a new cluster head. In this scheme it has a set of nodes (P), which are referred as "Ruling Nodes" having high voting capability over normal sensor nodes in elections. These "Ruling Nodes" are taken as the last '$|P|$'round cluster heads. This scheme follows a innovative strategy of "Threshold Based Reliability Calculation" for selection of Cluster head, which decides a particular node is compromised. During the elections every node gives either Positive or Negative votes for any of its active neighbors.

3.1. b Election of Cluster Head:

Within a Cluster, during Cluster – head election the nodes send its votes to the present Cluster- head. The nodes that don't have the sufficient energy (i.e. below a threshold level) are said to be compromised and ignores the votes if they are declared compromised in the previous rounds. All the other nodes poll the positive votes. The Parameters include Available Energy Resources, Hop Count and the neighbor's vote of the node based upon the Reliability. Considering the nodes votes and the neighbors votes CH is elected. As to increase the Network Lifetime, the nodes which have less available energy resources are made to be in sleep state. While transmitting data by using wakeup cycles, the nodes will participate in communication.

3.1. c Reliability Calculations:

The key factor which degrades the performance of Wireless sensor network (WSN) is consumption of energy .In a Homogenous Environment dealing with a clustered based hierarchical network, nodes sense the data and forward the data to the cluster head using the routing protocol. When the intermediate nodes forward the information, some amount of energy is consumed due to which the node may fail. This condition may lead to unreliable service. While sending a message to the cluster head, sensor node selects one of its neighbors and forwards the message through that neighbor. If all the messages forwarded through that neighbor reaches the cluster head then it makes its "Reliable" entry for that forwarding neighbor as "1" else it makes its "Reliable" as 0.A sensor node finds out whether the messages sent through the neighbor have reached the cluster head or not. A sensor node sends a vote for its neighbor as positive if the "Reliable value" =1 and negative if "Reliable value"= 0 and no vote if "Reliable Value" = 0.5.Reliable Values are preserved from round to round. A Sensor node forwards messages only through reliable neighbors.

3.1. d Voting and Winner Selection:

The candidates for cluster head are selected using following criteria [17]:

- Node should be Reliable.
- Available Energy Resources
- Hop Count.

During the election process every node sends its votes to the cluster head. Present cluster head ignores the votes from the nodes that are declared as compromised in the previous rounds. The number of votes polled for each sensor node is calculated. For each node in the cluster, the cluster head process only the negative votes. Then if the number of negative votes for a node crosses threshold (T) percentage of its total votes then it is declared as a compromised node. The positive votes of nodes, which are not compromised ever, are considered as candidates for the selection of cluster head. The present cluster head process the positive votes of candidate nodes. It calculates the positive vote weight for each candidate node unless the candidate node is a "Ruling Node" i.e. not in set P. Let 'W_n'is the normal vote weight and 'W_r' is "Ruling node" vote weight. If there are'X_1' normal node votes are positive and 'X2' ruling node votes are positive then positive reliable vote weight is(W_n*X_1 $+W_r*X_2$). Normally the ruling nodes are reliable and $W_r >>W_n$. Credit Weight is calculated for each candidate node to select the winner. The Credit Weight includes Positive reliable vote weight $P_{V\,i}$, Hop count of the node Hop_i and Available Energy Resource E_i.
The credit Weight is calculated as follows:
$W_{credit} = P_{relaible}\, P_{V\,i} + P_{hop}\, Hop_{\,i} + P_{energy}\, E_i$.

$P_{relaible}$, P_{hop}, P_{energy} are the amount of preference given to reliability, hop and energy criteria respectively. The node, which gets the highest weighted credit, is selected as new cluster head. The present cluster head handovers to the new cluster head. From now the present cluster head behaves as normal node and behaves as 'ruling node' for the next rounds. This information is intimated to other nodes in the cluster.

3.2 Cluster Formation:

Once the nodes have elected themselves to be cluster heads using the probabilities, the cluster head nodes must let all the other nodes in the network know that they have chosen this role for the current round. To do this, each cluster head node broadcasts an advertisement message (ADV) using non-persistent carrier sense multiple access (CSMA) MAC Protocol. This message is a small message containing node's ID and a header that distinguishes this message as an announcement message. Each non-cluster head determines its cluster for this round by choosing the cluster head that requires the minimum communication energy, based on the received signal strength of the advertisement from each cluster head. After each node has decided to which cluster it belongs, it must inform the cluster head node that it will be member of the cluster. Each node transmits a join -request message (Join- REQ) back to the chosen cluster head using a non-persistent CSMA MAC Protocol. The Cluster – heads set up a TDMA schedule and transmits this schedule to the nodes in the cluster.

3.3 Data Collection and Transmission:

3.3. a Latency:

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When the sensor node detects the event, information should be forwarded to the base station i.e., sink. In the cluster-based approach, the sensed node will transmit to the cluster head through the neighboring nodes. Cluster head performs data aggregation and transfers the information to the sink. As we are dealing with centralized TDMA approach, cluster head assigns the time slots to all the nodes in the cluster. Nodes naturally enable duty cycles by turning on their radio only during their own slots and sleep rest of the time, which helps to avoid collision and enhance the energy. The nodes transmit the information received or sensed in their respective time slots. The main drawback of TDMA based schemes is nodes have to wait for their own slots to transmit leading to latency. For mission critical applications latency is the important attribute. Our approach is a balanced approach between energy and Latency. In our scheme the wakeup schedule is used which will have a transition from TDMA approach to On Demand for critical information, which should be transmitted continuously, so latency can be reduced. The information sensed by the node will be stored, compared and transmitted to the cluster head. In the normal phase i.e. when the event is sensed the information will be stored and transmitted. The nodes will be transmitting in its slots assigned by the cluster head considering as low priority data. Nodes will be in sleep state for a long duration and will wakeup to transmit in their specified slots. This approach avoids collision, enhances energy efficiency. In the wakeup phase, when the node senses the event, the information is compared with the previous transmitted information, which is available. If the variation is above or equal to the threshold value, the node considers the data as critical and treats as a high priority. The high priority data should be transmitted to the base station immediately without latency. The wake up radio of each sensor will be awake for T_{listen} duration. When sensed nodes want to transmit a high priority data, it transmits a wakeup tone signal on the channel. The signal lasts for duration greater than slot time. T_{signal} >slot time.

Node 1	T_{listen}	Node 2	T_{listen}	Node 3	T_{listen}

Fig1.Frame structure.

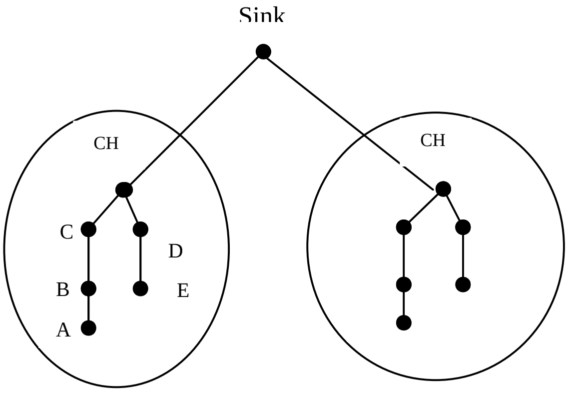

Fig 2.Multi-hop Cluster

In the normal phase, assume B is transmitting in its slot and after completing B's transmission C will take over the slot and transmits to the Cluster head. If A has sensed a high priority data, it has to wait for a time until C completes which leads to latency. In our approach we are modifying the TDMA frame format such that after the time duration allocated to each node all the nodes listen for duration T_{listen} .If nodes have not recognized any T_{signal} during the listen period, normal phase will be operated. Considering the example as the node want to transmit high priority data, it will transmit a wakeup tone signal, which will be recognized by all the nodes in the path during the listen period. We are making the nodes wake up on demand, all the nodes will wakeup and send an acknowledgement. A can transmit to the cluster head continuously with out latency.

4. Simulation

We assume that 100 sensor nodes are randomly distributed with dimensions 50 * 50. Every node senses the event, reports the data to its CH. The CH in each cluster aggregates and delivers to the sink. We have set the minimum probability for becoming a cluster head. The Simulation has been carried using ns-2.
We have compared our proposed RLL-MAC with LEACH and DMAC.

Figure 3 shows the packet latency obtained by three protocols based on the Number of sources. RLL-MAC performs far better.

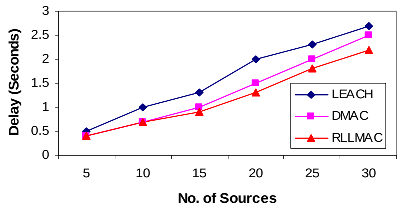

Fig 3 Packet Latency

Figure 4 specifies the delivery of packets form the node to the cluster head. As the number of sources increases the delivery ratio has been increased in RLL-MAC.

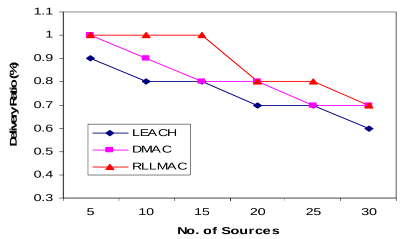

Fig 4 Delivery Ratio

Figure 5 and 6 shows the energy and network lifetime. RLL-MAC is compared with DMAC and LEACH. Energy efficiency will lead to increase the network lifetime.

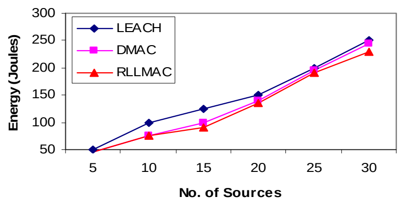

Fig 5 Energy

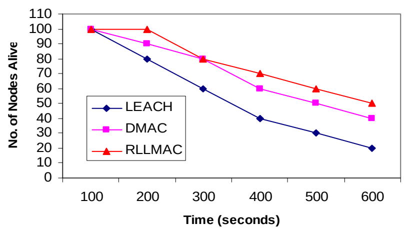

Fig 6 Network Lifetime

5. Conclusion

In this paper, we proposed a new cluster based Reliable and Low Latency Medium Access Control Protocol to reduce latency and to achieve reliable service. In the election of cluster head residual energy, hop count and reliability are considered which lead to increase the network lifetime. In addition, RLL-MAC consumes less energy in the normal phase and achieves lower latency in wakeup phase considering the criticality of information. RLL-MAC is more suitable for event critical applications in wireless sensor networks.

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