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Analysis of Hierarchical based MAC in Wireless Sensor Network

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Abstract: Medium Access Control with Overlapped Schedules for wireless sensor networks has been used to prolong wireless sensor network lifetime. In this technique the sensors are alternate between sleeping and awaking period. During the sleeping period, there is no energy consumption due to communication. However, the MAC algorithm has to ensure the awaking period of sensors sufficiently overlaps in order to allow nodes to communicate with each other. This dissertation proposes an algorithm that arranges the nodes in the form of hierarchical i.e. tree based. The nodes of the same level have overlapped schedules. The nodes of the same level get synchronized. It reduces the energy consumption as well as the delay due to the limited communication between the nodes. The proposed algorithm is implemented using the NS2 and the PDR, E2Edelay and the energy consumption is calculated to analyze the performance of the proposed and existing protocol. The simulation results confirm the better performance of the proposed protocol as compared the existing protocol. The increase in PDR, decrease in the E2Edelay and the decrease in the energy consumption of the proposed protocol as compared to existing protocol show better performance of proposed protocol as compared to exiting protocol. It means the life of the node get increased i.e. enhanced network life time.

1. Introduction

Recent advances in micro-electro-mechanical systems, low power and highly integrated digital electronics have led to the development of micro-sensors [1]. Such sensors are generally equipped with data processing and communication capabilities. These sensors have the ability to communicate either among each other or directly to an external base station (BS). A greater number of sensors allow for sensing over larger geographical regions with greater accuracy. These sensors can be networked in many applications that require unattended operations, hence producing a wireless sensor network (WSN) [2].

Definition : Wireless sensor networks (WSN) are highly distributed networks of autonomous small, lightweight sensors (nodes) in large numbers to monitor physical or environmental conditions by the measurement of temperature, sound, vibration, pressure, motion or pollutants and to cooperatively pass their data through the network to a main location (often called a sink) [3].

A Wireless Sensor Network (WSN) consists of a large set of sensor nodes that cooperate to monitor environmental conditions (e.g., temperature, precipitation, and radio-activity) in a given geographic area. WSNs are often designed for long term operation in remote unattended environments, despite the limited battery capacity of the wireless sensor nodes. Since data transmission is an energy-intensive task, energy aware data gathering techniques are used to extend the lifetime of the WSN. An effective way to conserve energy is to avoid reporting redundant data that occurs due to the spatial correlation between nearby readings. However, minimum cost network correlated data gathering is NP-complete [4].

2. Architecture of WSN

As sensor networks move towards increasing heterogeneity, the number of link layers, MAC protocols, and underlying transportation mechanisms increases. System developers must adapt their applications and systems to accommodate a wide range of underlying protocols and mechanisms. However, existing communication architectures for sensor networks are not designed for this heterogeneity and therefore the system developer must redevelop their systems for each underlying communication protocol or mechanism. To remedy this situation, no of communication architecture was presented such as the SP architecture by Polastre et al. [5]. SP does not specify any protocol headers therefore it leaves the problem of adapting to the network protocols to the application programmer. Communication architecture the Chameleon architecture was proposed by Adam dunkels et al. it consists of two parts: the Rime communication stack and a set of packet transformation modules. The Chameleon architecture is designed to be able to adapt to a variety of different underlying protocols and mechanisms while being expressive enough to accommodate typical sensor network protocols.[6]

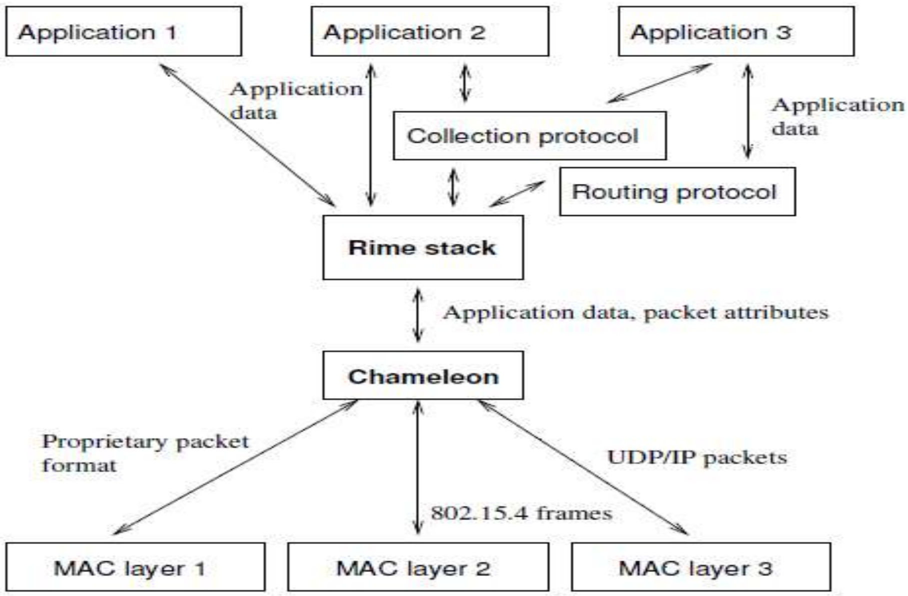

Figure1.1: The chameleon architecture

2.1 Clustering in WSN (Wireless Sensor Network)

It is widely accepted that the energy consumed in one bit of data transfer can be used to perform a large number of arithmetic operations in the sensor processor. Moreover in a densely deployed sensor network the physical environment would produce very similar data in near-by sensor nodes and transmitting such data is more or less redundant. Therefore, all these facts encourage using some kind of grouping of nodes such that data from sensor nodes of a group can be combined or compressed together in an intelligent way and transmit only compact data. This can not only reduce the global data to be transmitted and localized most traffic to within each individual group, but reduces the traffic and hence contention in a wireless sensor network. This process of grouping of sensor nodes in a densely deploy enlarge-scale sensor network is known as clustering. The intelligent way to combined and compress the data belonging to a single cluster is known as data aggregation.

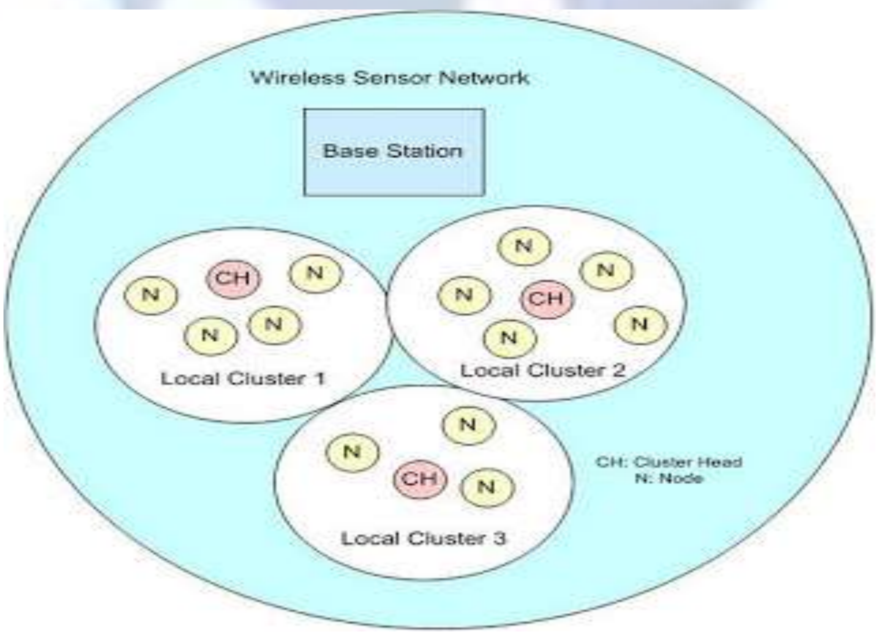

Figure 1.2: clustering in WSN

There are some issues involved with the process of clustering in a wireless sensor network. First issue is, how many clusters should be formed that could optimize some performance parameter. Second could be how many nodes should be taken into a single cluster. Third important issue is the selection procedure of cluster-head in a cluster. Another issue that has been focused in many research papers is to introduce heterogeneity in the network. It means that user can put some more powerful nodes, in terms of energy, in the network which can act as a cluster-head and other simple node work as cluster-member only. Considering the above issues, many protocols have been proposed which deals with each individual issue.[7]

2.2 Overview of MAC Protocols

In the broadest terms, a wireless network consists of nodes that communicate by exchanging packets via radio waves. These packets can take one of two forms. A unicast packet contains information that is addressed to a specific node, while a multicast packet distributes the information to a group of nodes. The MAC protocol simply determines when a node is allowed to transmit its packets, and typically controls all access to the physical layer. The specific functions associated with a MAC protocol vary according to the system requirements and application. For example, wireless broadband networks carry data streams with stringent quality of service (QoS) requirements. This requires a complex MAC protocol that can adaptively manage the bandwidth resources in order to meet these demands. Design and complexity are also affected by the network architecture, communication model, and duplexing mechanism employed. [8]

1.2.1 Problems for MAC to deal with

a) Bandwidth efficiency must be maximized.
b) Real-time traffic support should be provided.
c) Synchronization is also needed sometimes e.g. TDMA.
d) It shared broadcast medium therefore collisions must be avoided/minimized.
e) There is Lack of central coordination. [9]

1.2.2 Design goals of Mac Protocols

a) Operation of the protocol should be distributed.
b) Should support real-time traffic.
c) The access delay must be minimized.
d) Available bandwidth must be utilized efficiently.
e) Fair bandwidth allocation to competing nodes.
f) Control overhead must be minimized.
g) The effects of hidden/exposed terminals must be minimized.
h) Must be scalable.
i) Should minimize power consumption.
j) Should provide synchronization between nodes.[9]

2.3 Classification of MAC protocols

.Despite the great diversity of wireless systems, there are a number of well known MAC protocols whose use is universal.[10]

a) S-MAC

Locally managed synchronizations and periodic sleep listen schedules based on these synchronizations form the basic idea behind the Sensor-MAC (S-MAC) protocol [11]. Neighboring nodes form virtual clusters to set up a common sleep schedule. If two neighboring nodes reside in two different virtual clusters, they wake up at listen periods of both clusters. A drawback of S-MAC algorithm is this possibility of following two different schedules, which results in more energy consumption via idle listening and overhearing. Schedule exchanges are accomplished by periodical SYNC packet broadcasts to immediate neighbors. The period for each node to send a SYNC packet is called the synchronization period. Collision avoidance is achieved by a carrier sense, which is represented as CS in the figure. Furthermore, RTS/CTS packet exchanges are used for unicast type data packets. An important feature of S-MAC is the concept of message-passing where long messages are divided into frames and sent in a burst. With this technique, one may achieve energy savings by minimizing communication overhead at the expense of unfairness in medium access. Periodic sleep may result in high latency especially for multi-hop routing algorithms, since all immediate nodes have their own sleep schedules. The latency caused by periodic sleeping is called sleep delay in [11]. Adaptive listening technique is proposed to improve the sleep delay, and thus the overall latency. In that technique, the node who overhears its neighbor's transmissions wakes up for a short time at the end of the transmission. Hence, if the node is the next-hop node, its neighbor could pass data immediately. The end of the transmissions is known by the duration field of RTS/CTS packets.

Advantages: The energy waste caused by idle listening is reduced by sleep schedules. In addition to its implementation simplicity, time synchronization overhead may be prevented with sleep schedule announcements.

Disadvantages: Broadcast data packets do not use RTS/CTS which increases collision probability. Adaptive listening incurs overhearing or idle listening if the packet is not destined to the listening node. Sleep and listen periods are predefined and constant, which decreases the efficiency of the algorithm under variable traffic load.

b) Wise MAC

Wise MAC is a medium access control protocol developed by CSEM and designed for the Wise NET™ wireless sensor network (WSN). Wise Stack is a complete communication stack based on Wise MAC that also includes a self-configuring cluster-tree routing protocol and a host controller interface (HCI) for interacting with the communication module. Clock synchronization is also available Wise MAC is a low power MAC protocol specially developed for WSN [12] in combination with the Wise NET SoC. It is also available on off-the-shelf hardware such as Chipcon radios.

Wise MAC is a single channel contention protocol based on non-persistent carrier sense multiple access (CSMA). Non-persistent CSMA has been combined with preamble sampling to mitigate idle listening. The preamble sampling technique consists in regularly sampling the medium to check for activity. All nodes in a network sample the medium with the same constant period. Their relative sampling schedule offsets are independent (no network wide synchronization). If the medium is found busy, a node continues to listen until a data packet is received or until the medium becomes idle again.

At the transmitter, a wake-up preamble of size equal to the sampling period is transmitted in front of every data packet to ensure that the receiver will be awake at the start of the data portion of the transmission. This technique enables very low power consumption when the traffic is very low as it is usually the case in WSN. It provides the lowest possible power consumption in the absence of traffic and for a given wakeup latency using a conventional receiver. To reduce consumption further, Wise MAC minimizes the length of the preamble by learning and exploiting the sampling schedule of the direct neighbor nodes.

To use a wake-up preamble of minimized size, the sampling schedule of a neighbor is learned, or refreshed, during every data exchange by piggybacking in the acknowledgement messages the remaining time until the next sampling instant. Every node keeps a table of sampling time offsets of all its usual destinations up-to-date. Since a node will have only a few direct destinations, such a table is manageable even with very limited memory resources. The duration of the wake-up preamble must cover the potential clock drift between the clocks at the source and at the destination. This drift is proportional to the time since the last re-synchronization (i.e. the last time an acknowledgement was received) but cannot exceed the wake-up period. Systematic collision situations eventually introduced by this synchronization are mitigated using a small wake-up preamble of randomized size. In short, Wise MAC:

- Does not require any setup signaling
- Is completely asynchronous and does not rely on a network wide synchronization
- Reduces overhearing to its minimum
- Eliminates idle listening
- Mitigates the hidden node effect [13]

c) Traffic-Adaptive MAC Protocol (TRAMA)

TRAMA [14] is a TDMA-based algorithm and proposed to increase the utilization of classical TDMA in an energy efficient manner. It is similar to Node Activation Multiple Access (NAMA) [15], where for each time slot a distributed election algorithm is used to select one transmitter within two-hop neighborhood. This kind of election eliminates the hidden terminal problem and hence, ensures all nodes in the one-hop neighborhood of the transmitter will receive data without any collision. However, NAMA is not energy efficient, and incurs overhearing. Time is divided into random-access and scheduled-access (transmission) periods. Random-access period is used to establish two-hop topology information where channel access is contention-based. A basic assumption is that, by the information passed by the application layer, MAC layer can calculate the transmission duration needed which is denoted as SCHEDULE_INTERVAL. Then at time t, the node calculates the number of slots for which it will have the highest priority among two-hop neighbors within the period [t,t+ SCHEDULE_INTERVAL]. The node announces the slots it will use as well as the intended receivers for these slots with a schedule packet. Additionally, the node announces the slots for which it has the highest priority but will not be used. The schedule packet indicates the intended receivers using a bitmap whose length is equal to the number of its neighbors. Bits correspond to one-hop neighbors ordered by their identities. Since the receivers of those messages have the exact list and identities of the one hop neighbors, they find out the intended receiver. When the vacant slots are announced, potential senders are evaluated for re-use of those slots. Priority of a node on a slot is calculated with a hash function of node's and slot's identities. Analytical models for the delay performances of TRAMA and NAMA protocols are also presented and supported by simulations [14]. Delays are found to be higher compared to contention-based protocols due to higher percentage of sleep times.

Advantages: Higher percentage of sleep time and less collision probability is achieved compared to CSMA based protocols. Since intended receivers are indicated with a bitmap, less communication is performed for multicast and broadcast type of communication patterns compared other protocols.

Disadvantages: Transmission slots are set to be seven times longer than the random access period [14]. However, all nodes are defined to be either in receive or transmit states during the random access period for schedule exchanges. This means that without considering the transmissions and receptions, the duty cycle is at least 12.5 %, which is a considerably high value. For a time slot, every node calculates each of its two-hop neighbors' priorities on that slot. In addition, this calculation is repeated for each time slot, since the parameters of the calculation change with time.

d) SIFT

Sift [16] is a MAC protocol proposed for event-driven sensor network environments. The motivation behind Sift is that when an event is sensed, the first R of N potential reports is the most crucial part of messaging and has to be relayed with low latency. Jamieson et al. use a non-uniform probability distribution function of picking a slot within the slotted contention window. If no node starts to transmit in the first slot of the window, then each node increases its transmission probability exponentially for the next slot assuming that the number of competing nodes is small. In [16], Sift is compared with 802.11 MAC protocol and it is showed that Sift decreases latency considerably when there are many nodes trying to send a report. Since Sift is a method for contention slot assignment algorithm, it is proposed to co-exist with other MAC protocols like SMAC. Based on the same idea, CSMA/p* is proposed in [17] where p* is a non-uniform probability distribution that optimally minimizes latency. However, Tay et al. state that Sift has a distribution approximate to CSMA/p*.

Advantages: Very low latency is achieved with many traffic sources. Energy consumption is traded off for latency. However, when the latency is an important parameter of the system, slightly increased energy consumption must be accepted. It could be tuned to incur less energy consumption.

Disadvantages: One of the main drawbacks is increased idle listening caused by listening to all slots before sending. The second drawback is increased overhearing. When there is an ongoing transmission, nodes must listen till the end in order to contend for the next transmission which causes overhearing. Besides, system-wide time synchronization is needed for slotted contention windows. That is why, the implementation complexity of Sift would be increased for the protocols not utilizing time synchronization.

e) DMAC

Converge cast is the mostly observed communication pattern within sensor networks. These unidirectional paths from possible sources to the sink could be represented as data gathering trees. The principal aim of DMAC [18] is to achieve very low latency, but still to be energy efficient. DMAC could be summarized as an improved Slotted Aloha algorithm where slots are assigned to the sets of nodes based on a data gathering tree. Hence, during the receiving period of a node, all of its child nodes has transmitted periods and contend for the medium. Low latency is achieved by assigning subsequent slots to the nodes that are successive in the data transmission path.

Advantages: DMAC achieves very good latency compared to other sleep/listen period assignment methods. The latency of the network is crucial for certain scenarios, in which DMAC could be a strong candidate.

Disadvantages: Collision avoidance methods are not utilized, hence when a number of nodes that has the same schedule (same level in the tree) try to send to the same node, collisions will occur. This is a possible scenario in event-triggered sensor networks. Besides, the data transmission paths may not be known in advance, which precludes the formation of the data gathering tree.

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