Mobility Aware Hybrid Medium Access Control protocols in Wireless Sensor Networks

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***Abstract*: Mobility of nodes in Wireless Sensor Networks brings many communication challenges like frequent topological changes, energy efficiency, collision rate and latency. To address these challenges, most of the researchers focused on Mobility aware Hybrid MAC protocol design to improve overall network performance which transforms between contention and schedule-based approaches. The techniques used in these protocols, adjust the duty cycle according to mobility of nodes and also use suitable mobility detection algorithms to handle mobility in an efficient manner. In this paper, mobility parameters, types, models and detection algorithms are discussed and provides a comprehensive study of mobility aware hybrid MAC protocols.**
***Keywords*:** Mobility, Hybrid, MAC protocol, Mobile sensor Network, Wireless Sensor Network**.**

I. Introduction

The Wireless Sensor Network (WSN) is formed with large number of tiny, inexpensive light weight devices capable of sensing, communication, computation and provides bridge between physical world and virtual world [1]. The WSN find wide range of applications including military, healthcare, automobile, forest fire detection, habitat monitoring of animals, warehouse monitoring and it is limited to the human perseverance [2][3]. A sensor node is battery powered, has limited sensing range and limited processing power. The major challenges in WSN are energy efficiency, robustness, responsiveness, adaptation, self-organization, scaling, heterogeneity, privacy and security [4][5]. In-order to utilize the constrained resources at node in an efficient manner, MAC protocol to be intended carefully to increase the life time of node and network performance. The primary functionality of MAC protocol is to share the common resources among the contending nodes in possible manner [6].

The performance of WSN largely depends on designing of MAC protocols and the major problem to be considered in designing of MAC protocols are distributive operation, synchronization, access delay, bandwidth utilization, hidden node and exposed node problem, real time traffic support, rate adaptation, power control [7][8]. The static sensor nodes have limited sensing range and they can't cover large physical environment. So, they can't fit to some applications like disaster management, healthcare monitoring, emergency operations and these applications needs inherent node mobility. The Mobility is required to improve the communication capacity and increases the communication coverage range. The mobility of node poses many challenges at modeling of MAC protocol. The selection of mobility MAC protocol relies on mobility parameters such as latency, energy efficiency, minimum power consumption and throughput. When node is mobile, there is a possibility of link break and deterioration in the link quality. If the node finds decrease in the link quality, then transmits the whole data with higher data rate and handover the data transmission on to the better link before the existed link breaks completely.

Earlier surveys [10][11][12][13][14][15][16][17], missing to present a comprehensive survey on the mobility aware MAC protocols for WSNs. For example, in [10] focused upon the mobility models, patterns and estimation, instead focusing on mobility aware MAC protocols in the literature. In [12], presents mobility models, types and estimation thoroughly but covered only a small number of MAC protocols. In contrast, [16] author excludes the mobility effects and focus only on MAC protocols. A more recent study by [17], presents mobility models, types, detection and classify the MAC protocols. These authors have not covered Hybrid MAC protocols in detail.

This article provides a comprehensive and intensive study of overview of the state-of-the-art in mobility aware MAC protocols for WSN. We discuss mobility types, mobility patterns, mobility models and mobility estimation and detection. Here, based on medium access mechanism the mobility-aware MAC protocols are classified into four groups. In this paper the performance of the existing MAC protocols such as power consumption, throughput, scalability, and latency as compared. We discuss the pros and cons of these protocols in the discussion section.

The major contributions of this paper as follows:

1. It delivers a comprehensive synopsis of mobility characteristics such as pattern, model, types, estimation and detection.
2. It analyses the state-of-the-art of mobility aware hybrid MAC protocols in WSNs.
3. It points out the discussions and future research directions in mobility aware hybrid MAC protocols in WSNs.

This paper is structured as, Section 2 describes fundamental aspects of mobility types, patterns, models, estimation, detection and mobility handling in the MAC sublayer. Comprehensive review on slotted TDMA based, common active/sleep, preamble sampling and hybrid mobility-aware MAC protocols are overviewed in the Section 3,4,5,6 respectively. Compare the performance of the existing MAC protocols such as power consumption, throughput, scalability, and latency have been presented in section 7. Section 8 provides challenges, issues and design considerations for future MAC protocols for mobile sensor networks. Finally, conclusions are given in Section 9.

II. Overview of Mobility

Mobility of node brings many communication challenges in MWSN including frequent topological changes and increases collision rate, which need to be resolved. Mobility is an inherent feature of WSN as either node can mobile or event can be mobile based on the application requirement. The type of node movement, direction, speed and rate of change of position affect the performance of MWSN and protocols are designed to handle the mobility in an efficient way without much degradation in the operation. Mobility in WSN is characterized by mobility type, pattern, models and detection mechanisms.

A. Mobility Types

The different types of mobility in WSN are node mobility, sink mobility, event mobility [64].

1) *Node mobility:* A node can freely move from one location to another location, due to this topology changes every time and mobility can be strong or weak [48]. The strong mobility happens when the node varies from its original location. Mobility causes deterioration in link quality, frequent changes in topology and increase collision rate in the contention-based protocols. The weak mobility occurs when node joins/leaves the network or experiences any hardware failures. The node mobility affects the performance of MAC protocol and communication bandwidth needs to be adjusted dynamically without effecting neighbor's communication. The nodes can mobile continuously or occasionally based on the application and if the nodes are mobile, they can cover large areas which may not be possible when the nodes are in static condition.

2) Sink Mobility: The sink node (base station) can be static or mobile and it is a final destination of node or data collector in WSN. The sink node itself moves and gathers data from nodes in the monitoring area is called as mobile sink. In stationary sink, the predecessor nodes of sink experience very fast battery draining which affects the node's life time [65]. To increase the life time of node, mobile sinks are introduced in the network. If the sink is mobile at high speeds, it affects the packet delivery ratio and overall protocol design. In, sink mobility classified into three types based on the pattern and data collection approach

i)Mobile base station: The base station is mobile to gather data from relay nodes and the main idea is to decrease the communication delay, energy utilization of relay nodes and optimize the overall network performance with random movement of mobile base station [66]. The communication delay is distributed eventually with the mobile base station. Base station is mobile at high speed, it can't complete all data transmission of relay nodes because of these packets are dropped at high rate based on mobility [67].

ii) *Mobile data collectors:* Placing of a greater number of relay nodes and providing interfaces for long range communication is expensive [68] and to avoid this, the mobile data collectors are introduced and data collectors move inside the sensing area to gather the data from relay nodes. Mobility of data collectors can be random mobility and predictable mobility. In the random mobility, the data collector moves randomly and collects sensed data from one hop nodes. The probability of transmission delay is high due to random movement of data collectors. However, in the predictable mobility, the static relay nodes can assume that moving patterns of data collectors, speed and time and this information is used by static nodes to schedule their active/inactive periods to transfer data

iii) *Rendezvous mobility:* It is a hybrid approach with the combination of mobile base stations and mobile data collectors. The rendezvous points are introduced on the path and sensor nodes send data to these points. The rendezvous points send data to the sink and the packet drop ratio can be reduced by these points.

3) *Event mobility:* The sampled information to be reported by node in a specific area is termed as an event. The event is mobile in some applications like intruder detection and boarder node detection etc. The nodes select coordinators to report the particular event.

B. Mobility Pattern

The mobility patterns of node depict the real movement of physical objects. Mobility patterns in [70] WSN are characterized as pedestrian mobility, vehicular mobility and dynamic medium mobility pattern. Pedestrian mobility handles with the physical 2-dimentional movement pattern of public such as walking styles. The vehicular mobility understands the vehicle movements with inbuilt sensors of vehicle. The vehicles communicate and swap information about traffic condition, speed, direction of other vehicles. All vehicles can move according to the street plan in one direction only. Dynamic medium mobility pattern characteristics are varied with respect to time and the mobility based on medium.

C. Mobility models

Mobility models estimate the mobility patterns of real physical objects location, velocity, and acceleration with respect to time [71]. A node moves freely in sensing environment without any restriction on mobility and chooses independent random direction, speed and destination.

1) *Random Way Point model (RWP):* The RWP model was proposed in [72], mobile node chooses one node as destination node and it move towards destination node with constant velocity from [0, V_{max}]. The node chooses its velocity and direction independent of other neighbor nodes. Once reached the selected destination, the mobile node pause for some time, again selects another random destination and moves in that destination direction. The mobility of a node can be determined by two important parameters, V_{max} and Tpause. If V_{max} is high and Tpause is low, it is a continuous mobile network. If V_{max} is low and Tpause is high then it indicates the stable network. By varying these two parameters V_{max} and T_{pause}, the random way point model can produce a greater number of mobility models. For continuous mobility of node, the pause time of mobile node (T_{pause} =0) must be zero. The memory less nature of this model gives impractical node movement but most commonly used because of its simplicity and uses uniform spatial distribution in the initial stage of simulation. As time increases, the random way point model transforms the uniform distribution into non-uniform distribution. Number of nodes is more in the center region and almost zero in boarder region in case of non-uniform distribution.

2) *Random walk model:* Random Walk mobility model is proposed [73], determine unexpected mobility of nodes and also special case of random way point model with T_{pause}=0. The mobile node changes its speed and direction according to time and doesn't use the previous mobility information to approximate future position of node in some applications.
The main limitation of the RWP and random walk models is they do not provide certain mobility uniqueness consist of spatial dependency, temporal dependency and geographic restriction.

D. Mobility detection

The mobility detection models are developed based on mobility models and mobility patterns. There are different methods to estimate mobility namely
1) *Linear model:* This model uses GPS [79] to estimate future position of node from current and past states of information. The Kalman and Extended Kalman filters [77] are used to estimate the future node position in mobile networks.
2) Information theoretic model: Node maintains past history of neighbor nodes, sinks and compression algorithm is applied to maintain the observed paths [80].
3) *Markov-Chain based model:* Markov chain is generated based on the states and behavior of nodes and also describe the environment restrictions [81].
4) *Pattern matching model:* A link is predicted with- pattern matching approach. The node patterns are stored and search for similar patterns, if the patterns are matched then predict the link [82].

E. Mobility Estimation

The node mobility can be estimated with the following localizations methods

1. RSSI: It uses radio propagation model to interpret signal strength into distance and select the distance between sender and receiver without much degradation in the link quality [83]. Most of the sensors have the function of RSSI, doesn't need extra hardware. It fails to provide accurate distance estimation because of multipath fading, interference and irregular signal propagation conditions.

2. SNR: It measures the link state and signal strength varies with respect to distance [84]. The signal quality is good when the distance between two nodes is less and vice-versa. It doesn't require any special hardware to measure signal strength.
3. GPS: It gives position of nodes in detail with the support of satellite communication. The node location can be found out when connected to Internet and it is always not possible especially in remote areas. It is expensive and consumes scare resource of node energy [98].
4. Anchor nodes: Anchor nodes are set of static nodes within the environment and these nodes periodically broadcast message to neighbor nodes [85]. After receiving broadcast message from one or more anchor nodes, the node can determine its location but a greater number of anchor nodes is placed to get accurate location of node in the monitoring area.

5. Triangulation and Trilateration method: Triangulation method is used to calculate node location with the distance between each node and the center node [86]. It requires expensive antennas to get accurate localization of nodes and locates each node within single-hop neighbors. Trilateration method, determine the relative location of node from the intersection of three known positions of neighbor nodes.

6. Time of Arrival (ToA): It measures the range between two ends with transmitting signal by predefined velocity to their neighbors [87]. Each node sends a signal to their neighbors, then transmission time and reception time are recorded based on the time variation, distance. It requires strict time synchronization between transmission and reception slots.

7. Angle of Arrival (AoA): It is used to estimate the comparative angle between two nodes and which can be further used in calculation of distance [88].

8. RFID: Radio frequency signals are used to identify the objects and communication takes place between reader and radio tag [89]. The reader reads data from radio tag and radio tag is attached to any object like vehicles, employer identification, highway Tollgates, and access cards etc.

9. Pedometers: It is a physical portable electronic device to measure the physical activity of a person. It counts the walking distance of a person who carry this pedometer in terms of motion of legs or movement of hand in steps [90].

10. Accelerometer: It's an electromechanical device to calculate acceleration forces [91]. These forces may be fixed or dynamic and find applications in Laptops, smart phones, cars, aircrafts, and digital cameras etc.

III. Scheduled based MAC Protocols

A node makes prior bandwidth reservation to support real time traffic. Here contention occurs during resource reservation phase and after this node can exclusively use the reserved bandwidth. Within the allocated slot, the node can schedule to transmit or receive data without any collision [30]. The nodes periodically exchange their schedules with neighbors to save node energy. The major limitation of this scheme is fixed slot allocation even though the node doesn't have any data to send/receive and needs synchronization between nodes. Another disadvantage of TDMA protocols is fixed size slot assignment, so it can't handle traffic dynamically by assigning variable length slots. But it avoids energy wastage in terms of collisions, idle listening, overhearing. The communicating nodes maintain synchronization to send and receive data by periodic exchange of beacons with neighbors. Once the node receives periodic beacons, it makes transmission according to neighbor schedules. A node schedules either to transmit/receive data in active state and goes to sleep state in inactive period.

Lightweight MAC (LMAC) [32] is a distributed TDMA type MAC protocol. Main idea behind LMAC [33] is increase the lifetime of network by diminishing the overhead occurred at physical layer and reduces design complexity. Each channel is divided into slots; each slot includes control and data transmission mechanism. The slot reservation can be done with listen, wait, discover and active states. However, this protocol allows node to gain one time slot in a frame. It restricts the utilization of channel.

TRAMA [34] is a slotted based protocol to allow variable traffic loads by adjusting the duty cycle. Each slot contains contention and schedule period. In contention period, node access the medium and gathers two hop neighborhood information in that slot whereas in schedule period node announces its schedules to alert the intended receivers. This scheme requires strict coordination among the communicating nodes and low duty cycle to save node energy. This static scheduling limits the performance in highly mobile environment and its performance depends on prediction of node mobility, appropriate mobility detection models [31].

Mobility-adaptive (MMAC) [35] is an extension to TRAMA protocol, every node known its location to predict mobility in the network and it can cope up with strong as well as weak mobility. MMAC has a major limitation that requirement of node position which is not always possible. Mobile cluster MAC (MC-MAC) [36] is an extension of LMAC [32] and GMAC [37] and suitable for group mobility. Each frame consists of static slots and mobile cluster slots to accommodate static and mobile nodes respectively with dynamic slot assignment based on node density in the network. The major limitation of this protocol is collisions cannot be avoided due to switching delay and limits bandwidth utilization.

ML-MAC [38] is an extended version of LMAC protocol to adapt the network with mobile sensor nodes. MobiSense [39] combines both MAC and routing layers to get efficient and reliable with low-latency handoff mechanism. TSEEC [40] is a hybrid scheme, it integrates TDMA and statistical TDMA techniques to improve the network energy efficiency and reduce congestion.

These scheduled protocols require strict coordination among the communicating nodes and performs well in static networks. TDMA based protocols handle mobility with dynamic adjustment of duty cycle to static and mobile nodes in a predictable network. This protocol does not perform well in case of unpredictable topological changes in networks. The efficient TDMA MAC protocols are able to detect mobility with past movement history of node and reduce energy consumption at node to increase its life time.

IV. Contention based MAC protocols

In contention, nodes are contented to access the medium, whichever node wins the contention then access the medium to send and receive data. The node senses the medium with carrier sense multiple access/collision avoidance (CSMS/CA) mechanism [30]. All nodes are treated equally to share the bandwidth without any prior reservation. As soon as the node is having data it will contend to access the medium with other neighbors, so collisions are more during the resource allocation phase and it cannot provide guaranteed bandwidth to support real time traffic. These collisions lead to wastage of node energy [20][21].

SMAC [22], contention-based protocol and fixed duty cycle with common active and sleep schedules. In [23], the nodes share their active/sleep durations with neighbors by those neighbor nodes schedule their transmissions in the active state of node and also avoid energy consumption at node. In active state, nodes can send/receive data with other neighbor nodes and goes to sleep state to avoid energy wastage of idle listening when the node is not in transmit/receive mode. It can't handle mobility effectively because of the fixed size common active/sleep periods.

Timeout-MAC (T-MAC) [24] is an extension of S-MAC and uses dynamic frame time adaption with changes in the topology. It achieves better energy savings over S-MAC but increased overhead and latency. DSMAC (Dynamic SMAC) protocol uses dynamic duty cycle based on the application requirement in [25]. Initially all nodes having same duty cycle and duty cycle can be increased/decreased based on traffic condition in the network by adding active schedules in the sleep period. In order to handle mobility, these protocols require a precise, energy-efficient mobility detection algorithms and adaption of duty cycle according to changes in the network.

MS-MAC [26] is an extended version of S-MAC to allow mobility in the network. The mobile nodes make quicker connection in new cluster at the expense of high energy consumption of border nodes. EMS-MAC [27], is variation of MS-MAC protocol to handle mobility efficiently to avoid energy wastage in the network. The mobility of node can be detected with RSSI and LQI of SYNC packets. The energy consumption is more at border and mobile nodes.

AM-MAC [28], introduces Virtual Cluster (VC) and supports mobility in network same as SMAC. Every node schedule is exchanged with neighbors through SYNC packet in a virtual cluster. If the mobile node enters into new VC, it learns about the schedules of that cluster by listening to SYNC packets. In [29], MD-SMAC protocol is designed by considering the advantages of MS-MAC and DSMAC and merging their concepts to handle mobility in an efficient manner.

In common active/sleep protocols, nodes contend to access the medium when they have data and needs low duty cycle mechanism to save power at nodes. These protocols perform well in static networks but in case of highly mobile networks its performance depends on mobility detection algorithms. In highly mobile networks, the duty cycle needs dynamic adaptation to changes in topology of network which leads to high energy consumption.

V. Preamble sampling protocol

In this, short preambles are used to initialize a communication between transmitter and receiver. The sender sends a preamble beacon signal to alert the receiver for upcoming data transmission then the receiver wakes up to receive data from the sender. If node ready to transfer data, first it sends a short preamble before the actual data transmission takes place. This low power listening short preambles improves channel utilization and reduces energy consumption. Preamble Sampling based MAC protocols doesn't require network wide synchronization and due to this they are suitable to support network mobility.

B-MAC [56] is basic preamble protocol with active and sleep schedules. B-MAC introduces Low Power Listening scheme [58] to achieve better energy efficiency, latency than S-MAC due to lack of control overhead. Wise MAC [59] uses short preamble and adapts preamble length according to traffic in the network. Wise MAC is a preamble sampling protocol with non-persistent CSMA. X-MAC [60] is similar to Wise MAC and using short preambles it achieves better energy efficiency and latency with handshaking approach than Wise MAC.

MOBMAC [63] is developed to solve issue of mobility due to Doppler shift. MA-MAC [61] is an extended version of X-MAC and provides better energy efficient, throughput, latency and equality among the nodes. Maintaining the two threshold values in MA-MAC is complex and threshold values highly depends on node density gives major limitation. MoX-MAC [62] is similar to X-MAC for static nodes and nodes uses short preambles, ACK for actual data transmission between sender and receiver. Mobile node has to wait back-off time prior to actual data transmission takes place. The collision probability for ongoing session is less in MoX-MAC.

In preamble sampling protocols, network is not needed wide synchronization among the nodes. It reduces the synchronization overhead at the cost of longer preambles but longer preambles introduce collisions and limits duty cycle. Some preamble protocols adjust preamble length according to mobility in the network and performance is improved by avoiding idle listening and decreased collision rate.

VI. Hybrid MAC protocols

Mobility aware hybrid MAC protocols combine the idea of the contention, schedule based and preamble sampling MAC protocols to improve performance of network. Hybrid protocols are further classified in to synchronous hybrid MAC and asynchronous hybrid MAC protocols based on synchronization. In this section, existing Mobility supported hybrid MAC Protocols are investigated.

A. Synchronous Hybrid MAC protocols

These protocols are developed by adopting the features of contention based and scheduled based synchronous protocols. It incorporates the advantages of both contention and scheduled based methods to conserve scare resources at node [41]. It uses CSMA/CA and TDMA scheme to switch between contention and reserved slots respectively and its performance relies on how efficiently shifts between TDMA and CSMA/CA mode. The major limitation of hybrid protocol is more control overhead, latency and energy wastage due to switching between two modes. Every channel is divided into control and data channel to exchange control and actual information. Each frame contains random access and schedule access slots to accommodate mobile nodes and fixed nodes respectively. These protocols dynamically switch between schedule and random-access schemes at the cost of increasing overhead.

1. MHMAC

Authors in [48] proposes a mobility adaption hybrid MAC protocol, it focuses on better latency in addition to energy efficiency in WSN. The main idea of this protocol is designing an algorithm to decrease the duty cycle to minimum in the presence of strong mobility in the network. MHMAC adopts the concept from the LMAC [32] schedule-based approach for reservation of slots to static nodes and Scheduled Channel Polling (SCP) contention-based approach for mobile nodes. In [48] the frame is arranged into static slots and mobile slots and Mobility Beacon broadcasts the mobility information to its neighbors at the beginning of each frame. Every node determines mobility using mobility estimation algorithm depends on RSSI. In this protocol, nodes can control multiple slots depend on mobility traffic. Cluster head (CH) will collect the new frame time, mobile to static node ratio and CH election is similar to LEACH [46]. If the network is static MHMAC performs similar to Scheduled based protocol, exhibits energy efficiency and delivery ratio is same as LMAC but latency is improved. When the network is highly mobile, latency is better than scheduling protocol but it is similar to contention protocol. Overall, MHMAC performs well in terms of latency even at high mobility. When mobility increases, contention may also increase leads to retransmissions. Hence the network energy efficiency decreases.

2. MEMAC

MEMAC [49] gives an adaptive and energy efficient mobility aware MAC protocol for MSNs. MEMAC is hybrid protocol integrates the advantages of CSMA and TDMA protocols for dynamic adjustment of topology and traffic conditions to realize energy efficiency. The frame length is varied depends on the mobility of network by estimating AR-1 model in [78]. In [49], protocol uses clustering phase similar to MMAC [35]. Network is partitioned into dynamic clusters and elect CH which handles both channel access and control frames. In this protocol nodes can access the channel in four stages. Firstly, Synchronization stage CH sends SYNC packets all nodes in the cluster. Secondly in Request/Leave/Join stage the nodes which are leave or join from the cluster should send a request to CH by sending short control message using random access slots. Thirdly, CH broadcast the schedule including TDMA slots within cluster in Schedule Calculation and Distribution phase. Using TDMA slot nodes send data to CH in data transfer Phase in last stage. Energy efficiency is enhanced by switching the nodes to sleep if they are not in the communication progression.

3. MAMAC

In [51] proposes MA-MAC protocol, which handles multi-hop networks based upon the mobile uniqueness of Node Units. Authors mainly focuses on design of a MAC protocol for Tactical Data Link network which deal with the issues caused by performance optimization in dynamic network. MA-MAC is a hybrid scheme it merges the benefits of RT (reservation-based

transmit mode) get the concept from E-ASAP and CT (contention-based transmit) mode. First slot is reserved to new NUs. Except for first slot every slot has the equal length and separated into two fields: Contention Window Field (CWF) and packet field (PF). CWF length is same as Hello Information (HI) and maximum propagation delay for Secondary NUs. PF is used for accessing the slot which transmission of the NU. HI field broadcast "hello" messages collective with instant mobility value are sporadically sent to one-hop neighbors. As soon as the NU acquires data from neighbors in its area, it starts assigning the slots dynamically. Depending on mobility level each NU switch between RT and CT mode.

4. V-MAC

In [52] proposes Versatile MAC is designed with a fixed frame length and integrates the benefits of scheduled MAC for energy efficiency and contention MAC for short transmission delays. It is an extension to TDMA protocol and supports mobility. The authors not used clustering mechanism, hence VMAC gives good results in short distance communication and it merges advantages of TDMA and 802.11. V-MAC uses fixed frame length consists of Random and schedule slots. The fixed Contention window (CW) is used as a back-off to reduce RTS (Request to Send) collisions within two hop neighborhood and data transmission. To get fair allocation of channel access for each node fixed CW size is used. The CW size and number of slots are proportional to number of nodes in two hop neighborhoods to handle mobility and number of transmission slots must be less than number of neighbors. It is a distributed schedule-based MAC protocol and does not include sleep synchronization which is not possible in contention-based protocols. Each frame is split into random access and schedule period for collision free transmission of data on the fixed reservation and transmission slot. Mobility in V-MAC can be detected by using GPS [57] and it is viewed as a communication means between the sender and receiver when both are either in stationary or mobile. The smaller frame length is used to increase throughput but increases energy consumption in one hop neighborhood. The packet delivery ratio is less in one hop neighborhood but increases delay.

5. CTh-MAC

Authors in [54] proposed CTh-MAC combine the features of CSMA and TDMA for mobile WSN. Nodes in network are divided into subsets according to the coverage region of sensor nodes to sink node. Proposed protocol is work in two schemes. Firstly, sink node assigns slots to all subsets based on the TDMA mechanism. Secondly, within each subset nodes are competing for communication based on CSMA/CA mechanism. The major focus of CTh-MAC is reducing energy utilization in high-speed mobile environment with position prediction algorithms and also improving the throughput of the networks.

B. ***Asynchronous Hybrid MAC protocols***

These protocols integrate the benefits of both preamble sampling protocols and synchronous approaches to provide improved performance with better channel utilization and reduce control overhead. In asynchronous protocols nodes follow individual schedules with sleep and awoke mechanism [55] without strict time synchronization between nodes. A node is in sleep state for long period of time and wake up for short period of time to check any ongoing data transmission. Each channel consists of control channel to exchange short beacons and data channel to send/receive data. Sender sends sporadic beacons up to intended receiver wakeup and each node periodically wakeup to listen beacons. Once the node listen beacon, it is in wake-up state until the sender sends the data and node goes to sleep state when the ongoing data transmission is completed. Asynchronous protocols are Scalable, robust and energy efficient depends on preamble lengths.

1. MMH-MAC:

In [50], introduces the Mobile Multimode Hybrid MAC protocol is an extension of MH-MAC. MMH-MAC works in scheduled and preamble sampling mode. It switches between asynchronous mode for energy efficiency and synchronous mode for higher throughput. The changing mode from synchronous to asynchronous nodes will give interference between them. To avoid interference cross layer mechanism is designed. To reduce interference initially synchronous nodes, terminate preambles and later network task will be modeled in synchronous idle slots. Increased SYNC frequencies with multiple transmissions at any slot are allowed to track faster nodes. In [50], it merges active interference alleviation by using Shut-up frame and passive interferences alleviation is based on asynchronous active time to increase the synchronous mode throughput in the occurrence of asynchronous node transmissions.

2. BN-MAC:

BN-MAC [53] integrates the concepts of contention approach which accommodates novel semi-synchronous to help the faster medium access and schedule mechanism helps to diminish the collision and overhearing difficulty. Border Node (BN) is type of a sink node that collects data from target and shares with other broader nodes as necessary. BN-MAC protocol is designed in four phases. All four phases are operated once throughout the setup process and also up to the network topology varies physically. Firstly, clusters will be formed based on One-hop neighbor node selection and slot allocation. In second phase, intra-semi-synchronous communication established between BN and nodes is handling with an asynchronous approach. Inter-synchronous communication among BNs in different clusters is managed with a synchronous method. In this scheme, BNs of all clusters are synchronized with neighbor clusters hence hidden terminal problem will not arise. In boarder node selection process, BN is elected periodically using the DBNSP model based on residual energy of node and signal strength. BN-MAC is

designed to address the problems of mobility, scalability and low power listening. The performance of Asynchronous hybrid protocols depends on adjustment of duty cycle to fixed and mobile nodes and also reduces interference between asynchronous and synchronous transmission.

Protocol/ Design concern	MH-MAC	ME-MAC	MA-MAC	V-MAC	CTh-MAC	MMHMAC	BN-MAC
Working Scheme	Synchronous	Synchronous	---	Synchronous	Synchronous	Synchronous & Asynchronous	Semi Synchronous
Mobility model	Random	Random way point	---	---	---	---	Pheromone Termite
Clustering	Yes	Yes	Yes	No	Yes	Yes	Yes
Energy efficient	No	Yes	No	Yes	No	Yes	No
Energy Consumption	More	Less	More	Less	More	Less	More
Reduces delay	No	Yes	Yes	No	No	Yes	No
Reduce Overhead	No	No	No	Yes	Yes	No	No
Network Scalability	No	No	Yes	No	No	No	Yes
Throughput	Less	Moderate	Moderate	Moderate	High	High	Less
Collisions	More	Less	Moderate	Less	Less	Less	Moderate

Table 1. Comparison of various mobility aware hybrid MAC protocols

VII. LEARNED LESSON & COMPARISON

The rapid development of MWSNs finds applications in surveillance, health care, disaster management etc. All these applications need efficient handling of mobility to improve coverage area and reduce energy consumption. These protocols are proposed to handle node or sink mobility in the network without compromising on throughput, energy efficiency, latency, scalability. These protocols mitigate the limitations of existed fixed duty cycle and schedule-based schemes. The behavior of these protocols depends on precise mobility detection methods based on speed, velocity and direction of movement of objects. The node mobility type, patterns and detection algorithms are briefly discussed in section II and key parameters in mobility estimation algorithms are mobility type and patterns.

Many of the Mobility aware hybrid MAC protocols use RSSI but its accuracy is poor. Some Mobility aware hybrid MAC protocols use AR-1 model which increases complexity and others use GPS, which is cost effective as well as increases energy consumption. The existed hybrid mobility aware MAC protocols for MWSNs concentrated on how to handle mobility without degrading overall performance. These Mobility aware hybrid MAC protocols are developed to provide optimum trade-off between energy efficiency and latency.

MH-MAC does not require exact node location information and uses mobility detection algorithm to handle mobility. It performs well in terms of latency under high mobility but the

major limitations are edge node problem, energy consumption increases with mobility, large communication overhead.
MEMAC protocol reduces delay and improves the packet delivery rate. It uses AR-1 model to estimate mobility but increases computation overhead and also suffers with network adaptability under high mobility scenario. ME-MAC reduces the delay and increases the throughput than MH-MAC.
MA-MAC provides less communication overhead under high mobility of nodes which improves channel utilization and reduces average packet delay. When network dynamic is high the average packet delay in MH-MAC and MA-MAC does not increase

significantly. VMAC uses GPS to detect mobility in network and channel reuse is used to avoid congestion in network. The small frame length improves throughput but increases energy consumption and overhead is more under large scale networks. CTh-MAC improves throughput under high-speed mobile transmission but increases energy consumption and delay.

MMH-MAC protocol, improve energy efficiency in asynchronous mode and provides enhanced throughput in synchronous mode. The major limitations of this scheme are switch between asynchronous and synchronous methods, scalability and edge node problem. BN-MAC follows semi synchronous approach to improve the lifetime of network significantly by dynamic selection of BN nodes. The BN election needs more control overhead which increases large energy consumption. BN-MAC exploits a low duty cycle and introduces a semi- synchronization approach. Dynamic selection of the border node significantly improves the lifetime of the entire network but when the border node energy drains out or moves out of the region the all nodes inside that region suffers with communication failure. The comparison of Mobility aware hybrid MAC protocols is shown in Table 1.

VIII. ISSUES AND FUTURE CHALLENGES

The recent research development of mobility aware hybrid MAC protocols for WSN has studied the performance of the network in the aspect of high and low mobility. The researchers presented possible solutions to accomplish a near-optimal performance. The hybrid MAC protocols were divided into four main groups based on their access method. Hybrid MAC protocols are developed by adopting the features of scheduled based, contention based and preamble sampling MAC protocols to achieve optimize results. However, some mobility aware MAC protocols use a dynamic frame time to switch from schedule to contention. Hence, packet overhead and latency are increases due to switching between two operation modes. To calculate the frame length, they need information of synchronize nodes in the clusters at the same time. It leads to increase in communication and computation overheads.

Preamble sampling protocols are rugged to dynamic changes of topology, as they do not need any prior topology information and time synchronization. Preamble sampling protocols consume less energy compared to scheduled MAC protocol in low traffic load. Furthermore, there is less research happened in the mobility aware hybrid MAC protocol with preamble sampling mechanism. So, there is much requirement of designing hybrid MAC protocols by combing preamble sampling with schedule slotted based as well as contention common active sleep period protocols. Further there is some other areas need to be enhanced these mobility aware hybrid MAC protocols as follows

Most of the researches are concentrated on only one or two parameters to develop mobility aware hybrid MAC protocol for consideration of QoS, it leads to unbalance mechanism. While designing protocol it is needed to consider the parameters latency, delay, jitter, maximizing the throughput and energy consumption. To achieve optimized performance of the network different layers of the protocol stack need to be interact and exchange the information. Change the architecture of the protocol stack, and combine the two or more layers into one that can result in better performance. However, there are existing protocols which combines MAC layer and Network layer. A cross-layer approach for mobility handling in WSNs can be helpful in avoiding duplication of information control and reducing overhead. There is much requirement of designing application specific mobility aware MAC protocols.

IX. Conclusions

In this article, a comprehensive study of mobility aware hybrid MAC Protocols in WSN is presented. The drawbacks of contention based, scheduled based and preamble sampling protocols are discussed in the context of mobility. The importance of mobility hybrid MAC protocols is discussed to overcome the limitations caused by contention based, contention less protocols. Different types of mobility patterns, models, types and various detection algorithms are discussed. This paper explored several mobility hybrid MAC protocols and compares their advantage and disadvantages discussed. Finally, the future research and development direction for mobility aware hybrid MAC protocols for WSNs has been presented.

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