A robust energy efficient MAC protocol design for Underwater sensor network

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Declaration

It is hereby declared that this thesis and any part of it has not been submitted elsewhere for the award of any degree or diploma.

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Abstract

In this examination work, a vigorous and vitality proficient Bidirectional Multi-Flow MAC convention (BMF-MAC) for Underwater Sensor Network is proposed to deal with multi-bounce multi-stream information trails so that numerous floods of data transmission proceed at the same time while modifying with changing traffic condition. The proposed MAC improves channel usage by presenting an information transmission strategy utilizing the bidirectional multi-stream parcel technique for sending different information bundles of a similar stream in the turn around course. So as to decrease of idleness, this convention is meant to plan more information transmission over different multi-jump streams for quick circulation of information. So as to complete the presentation investigation of the proposed BMF-MAC convention, a scientific model is inferred which incorporates the condition of vitality utilization, throughput and start to finish delay. At long last, execution examination between the proposed BMF-MAC convention and contemporary CMRT convention is appeared. Our correlation demonstrates that proposed convention outflanks the contemporary Cascading Multi-jump Reservation and Transmission (CMRT) convention as far as throughput, start to finish deferral and vitality utilization.

Chapter 1

Introduction

1.1 Introduction

Underwater Acoustic Sensor Network (UW-ASN) is an emerging technology that has a diverse set of applications for vehicles and vessels navigating below the surface of the water. Environmental monitoring, resource investigation, disaster recovery and military surveillance are some of the extensively used applications [5]. Such a network normally consists of a large number of distributed nodes that organize themselves into a multi-hop network. Each node has one or more sensors, embedded processors and acoustic modem, and is normally battery operated. Typically, these nodes coordinate to perform collaborative monitoring tasks over a predetermined area.

Medium Access Control (MAC) protocol in underwater sensor networks has an important role to enable the successful operation of the network. One fundamental task of the MAC protocol is to avoid collisions so that two interfering nodes do not transmit at the same time. The proposed protocols for UWSNs generally can be classed into three types: ALOHA-based, time division multiple accesses (TDMA)-based and carrier sense multiple access (CSMA)-based in recent year.

Underwater sensor nodes are expensive as well as the sensing areas of ocean environments are large. Therefore, the sparse network deployments and the widespread use of mobile sensors are required. Furthermore, underwater sensors sure from corrosion problem and the capacity of batteries are limited as well. Additionally, it is hard to access power sources such as solar in underwater, so the battery cannot be recharged in simple way [6]. The fundamental Different between terrestrial WSN and UW-ASN are discussed in the following. The propagation time of terrestrial WSN can be avoided as the network uses radio frequency (RF) electromagnetic signals with the speed of light (3 108 m=s) to transmit packet [7]. On the contrary, UW-ASN uses acoustic wave (1,500 m=s) as the communication carrier. As a result, the propagation delay will be one of the important characteristics due to the fact that the propagation time is much longer than RF electromagnetic signals. Thus, problem called -time uncertainty" arises. Furthermore, transmitting power consumption in UW-ASN is expensive. The transmitting power is typically 100 times more than the receiving power in acoustic links [8]. For this reason, some terrestrial protocols using packet exchange frequently are unsuitable when they are used in UW-ASN. Moreover, in underwater environment, the bandwidth is limited by the characteristics such as path loss, noise, multi-path, high delay variance, and Doppler-spread [9]. Hence, the physical media which are used in acoustic networks are characterized with long propagation delay, low data rate and high packet loss [2]. As a result, the wide variety of MAC protocols formerly proposed for wireless terrestrial networks do not perform well in underwater due to the above-mentioned uniqueness of underwater networks.

1.2 Motivation

While designing underwater MAC protocols; the long propagation delay is be-coming leading feature to be considered in underwater acoustic channels circumstances. More specially, the exchanging of control packets is time-consuming in handshaking-based MAC protocols. This causes a large signaling overhead. Furthermore, the end-to-end delay significantly rose while of multi-hop relaying take place in a hop-by-hop handshaking manner. By reserving the multi-hop channels at once with the help of cascading reservation control packets, CMRT [4] overcomes the problem of handshaking-based MAC protocols. Without stopping at intermediate Nodes, the CMRT protocol deliver the data packets in the same manner until they reach the destination node. Therefore, CMRT plays different role from other conventional MAC protocols by this multi-hop reservation approach and thus, employs for multi-hop transmission. Moreover, for improving channel utilization, the protocol adopts a packet-train method [12] by sending multiple data packets together with only one handshaking signal. Moreover, simultaneous transmission of regular and reverse data packets over a same flow cannot be held by this protocol. As a result, the protocol poorly respond to heavy traffic loads. Therefore, an energy e client MAC protocol with high channel utilization and low latency for UW-ASN in varying traffic conditions is necessary.

1.3 Related Work

The long propagation delay of the acoustic signal makes the designing of handshaking-based MAC protocol more complex to avoid any collision in under water environment. A number of works have been proposed to reduce handshaking significantly [3,7,10-14]. Some protocols have improved the channel utilization by sending multiple packets at once in a packet-train form [7, 10]. Furthermore, handshake-sharing approach is introduced in [3,11] has permitted multiple nodes to participate in a common handshake. Furthermore, some of the works adopted sender-initiated approach to provide solution while others adopted receiver-initiated approach to provide solution. In this thesis, we focus on the study of handshaking approach to improve performance of the sensor networks. The multiple-access collision avoidance (MACA) protocol uses the request-to-send (RTS)/clear-to-send (CTS) handshake for reserving the shared channel which is a popular terrestrial handshake-based MAC protocol [15]. For implementing MACA in an underwater environment, MACA for underwater (MACA-U) was pro-posed which can revise the state transition rules considering the long propagation delay [16]. However, due to the long propagation delay in the underwater acoustic Channel, the simple RTS/CTS exchange cannot fully address the hidden-node problem. Moreover, the requirement of increased time for exchanging the control packet makes the performance of the protocol severely constrained. Furthermore, a spatial unfairness problem arises due to the long propagation delay in underwater environment. The slotted floor acquisition multiple access (Slotted-FAMA) protocol, one of the pioneers MAC schemes, combines both carrier sensing and handshaking mechanisms that prevents collisions [17]. In this protocol, packets are transmitted at the beginning of a slot whose length is equal to the maximum propagation delay. However, the throughput performance is significantly reduced by the excessive length of the slot, though the protocol can prevent collisions caused by hidden nodes. Bidirectional concurrent MAC (BiC-MAC) protocol [18] improves the channel utilization by transmitting data packets to a sender-receiver pair simultaneously for each successful handshake. The protocol adopts a packet bursting method that allows the sender and receiver node pair to exchange multiple rounds of bidirectional packet transmissions. Thus, the entire set of data packets is actually transmitted over several discontinuous packet bursts. Therefore, single sender and receiver is considered for bidirectional data transmission. However, multi-flow scenario is not considered. A receiver-initiated MAC protocol named Receiver-Initiated Packet Train (RIPT) protocol is proposed in [10].

1.4 Research Objectives

Maximizing the network lifetime and throughput are the common objectives of sensor network research. The core objective of this thesis is to design a new energy efficient bidirectional multi-ow multi-hop medium access control protocol for underwater acoustic sensor networks under different traffic load patterns.During the process of designing this proposed protocol the following basic mile-stones are identified as the objectives of this thesis.

- To develop a new multi-own MAC protocol called BMF-MAC for multi-hop under water acoustic sensor networks in varying traffic conditions.

- To improve the channel utilization and to reduce the end-to-end delay of the networks.

- To carry out the performance analysis such as energy, throughput and latency of the proposed protocol.

- Finally, to investigate the efficiency of the proposed BMF-MAC protocol, a performance comparison between BMF-MAC protocol and other existing protocols will be carried out.

1.5 Organization of Thesis

This thesis consists five chapters. Brief description of its different chapter is as follows.

Chapter one briefly introduces MAC protocol of underwater sensor networks. Related researches regarding handshaking based MAC protocol as well as motivation and objective of this research are presented in this chapter.

Fundamentals of MAC protocol are explained in chapter two. Issues related to protocol design for the MAC sub layer of data link layer in OSI reference model and different types of medium access protocols (MAC) are illustrated in this chapter.

The details of the proposed BMF-MAC protocol are elucidated in Chapter three. In order to carry out performance analysis, an analytical model is derived which includes the equation of energy consumption, throughput, end to end delay, and frame error probability.

The performance of the proposed approach is investigated in terms of performance parameters such as number of throughput, end-to-end delay, and energy consumption in chapter four. Moreover, in order to show the e activeness of the proposed scheme, a performance comparison between proposed BMF-MAC protocol and existing CMRT protocol is carried out in this chapter as well.

Finally, chapter five concludes this thesis along with some limitations and future research scopes.

Chapter 2

Fundamental Issues of MAC Design

2.1 Introduction

Consequently, in this section, we portray the submerged acoustic condition and distinguish the real difficulties to the structure of MAC conventions for UWSNs.

2.2 Differences between Underwater and Terrestrial Sensor Networks

UWSNs comprise of a variable number of sensors and vehicles that are sent both at submerged and at the surface to perform cooperative checking assignments over a given region. To accomplish this goal, sensors and vehicles self-arrange in a self-governing system which can adjust to the attributes of the sea condition. The hubs can trade and share data among themselves and base stations.

Table 2.1 shows the difference of some features of WSN and UWSN. The main differences between terrestrial and underwater sensor networks are mentioned below:

1. **Power:** Because of higher separations and progressively complex sign handling at the collectors to make up for the impedances of the direct in submerged condition, the power required for acoustic submerged correspondences is higher than in earthbound radio interchanges.

2. **Memory:** Earthly sensor hubs have exceptionally restricted capacity limit. UW-sensors may should almost certainly do a few information storing as the submerged channel might be irregular.

3. **Cost:** Presently a days, earthly sensor hubs are ending up progressively reasonable. Then again, submerged sensors are costly gadgets. Since, submerged handsets are progressively intricate and solid equipment assurance is required in the extraordinary submerged condition.

4. **Deployment:** Earthly sensor systems are thickly conveyed. Then again, the arrangement is esteemed to be increasingly inadequate in submerged as the cost included and the difficulties related to the organization itself is high

5. **Spatial correlation:** From earthly sensors, the readings are frequently likened. Actually, this happens once in a while in submerged systems as the separation

Table 2.1: Difference between WSN and UWSN

Features	Terrestrial sensor networks	Underwater sensor networks
Communication medium	Air	Water
Communication carrier	Radio frequency	Acoustic wave
Transmission Speed	$3X10^8$ m/s	1,500 m/s
Deployment	Densely deployed	Sparsely deployed
Power	Lower compare to UWSN	Higher compare to WSN
Propagation delay	Negligible	Long
Cost	Less expensive	Expensive
Memory	Limited capacity	Higher compare to WSN

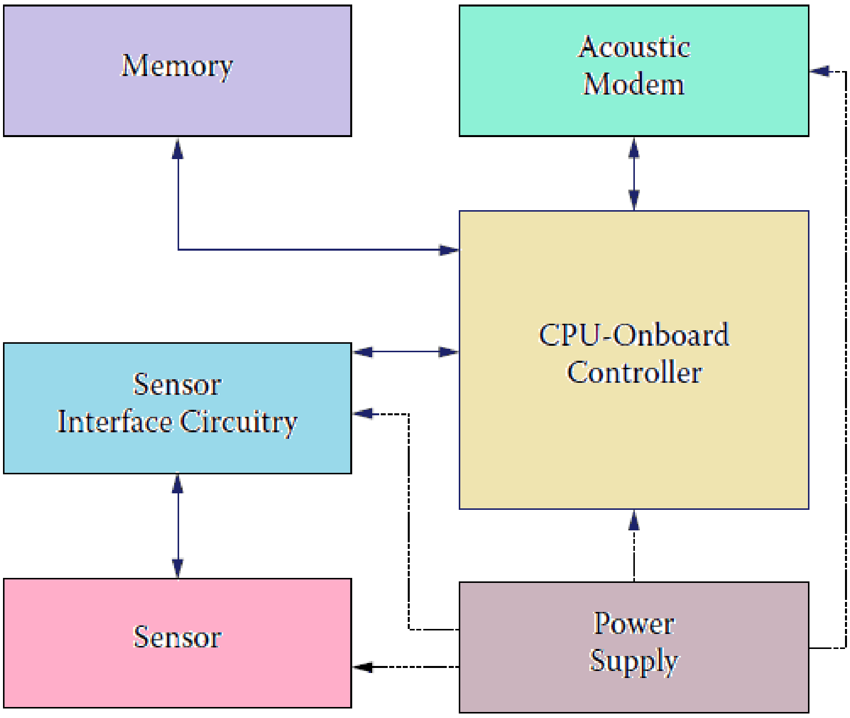

Figure 2.1: Internal architecture of an underwater sensor node

is high among sensors.

2.3 Underwater Sensor Hardware Design

In Figure 2.1, the run of the mill inside engineering of a submerged sensor is illustrated. The sensor contains a principle controller/CPU which is interfaced with an oceanographic instrument or sensor through a sensor interface hardware. The controller can get information from the sensor and store it in the on board memory. At that point the CPU forms information and send; it to other system gadgets by controlling the acoustic modem. The gadgets are commonly mounted on a casing that is secured by a PVC lodging. Continually, all sensor segments are secured by base mounted instrument outlines. This casings gives azimuthally omni directional acoustic interchanges and shields sensors and modems from potential effect of trawling gear, particularly in territories exposed to angling exercises. By lodging all segments underneath a position of safety pyramidal casing, in[21], the creator structure the securing casing to avoid trawling gear on effect [1].

The moves identified with the arrangement of minimal effort, low scale submerged sensors, are recorded as pursues:

- To grow more affordable, vigorous ”nano-sensors”, e.g., sensors dependent on nanotechnology is urgent.
- To improve exactness and accuracy of examined information for strong, stable sensors is vital; since sensor float of submerged gadgets might be a worry.
- To devise periodical cleaning systems against consumption, fouling is required, which causes impaction on the lifetime of submerged gadgets.
- For succinct examining of physical, concoction, and organic parameters, new coordinated sensors are required which can improve the comprehension of genius cesses in marine frameworks

2.4 Communication Architecture of Underwater Acoustic Sensor Networks

The submerged sensor arrange topology is an open research issue that requirements progressively expository and simulative examination from the exploration network. The correspondence engineering of submerged acoustic sensor systems are depicted in this area. Here we portray the reference structures which are utilized as a reason for dialog of the difficulties related with submerged acoustic sensor networks[22].

Static UW-ASNs are built up by sensor hubs that are moored to the base of the sea. There regular applications are ecological observing, or checking of submerged plates in tectonics [23].

Figure 2.2 presentations a reference engineering for submerged systems. Here, we watch a gathering of sensor hubs are secured to the base of the sea with profound sea stays. Submerged sensor hubs are interconnected to at least one submerged sinks (UW-sinks) with the assistance of remote acoustic connections. These are organize gadgets accountable for transferring information from the sea base system to a surface station. For the most part, UW-sinks are outfitted with two acoustic handsets called a vertical and a level handset. UW-sink utilizes the even handset for speaking with the sensor hubs. They can send directions and setup information to the sensors (UW-sink to sensors), gather observed information (sensors to UW-sink). Moreover, UW sinks utilize the vertical connection too. They can hand-off information to a surface station. Vertical handsets ought to be long range handsets for profound water applications as the sea can be as profound as 10 km. The surface station which is fit to deal with numerous parallel interchanges with the conveyed UW-sinks is furnished with an acoustic handset. Also, it is invested with a long range RF or potentially satellite transmitter to speak with the coastal sink (OS-sink) or to a surface sink (s-sink).

By means of direct links or through multi-hop paths, sensors are connected to UW-sinks . Each sensor directly sends the gathered data to the selected UW-sink in the first case. Though this is the easiest way to network sensors, it is less energy efficient. Because, the sink may be far from the node and the power necessary to transmit may decay with powers greater than two of the distance. Moreover, due to increased acoustic interference caused by high transmission power, direct links are very likely to reduce the network throughput. As in terrestrial sensor networks, for multi-hop paths condition, the data accomplished by a source sensor is forwarded by intermediate sensors until it reaches the UW-sink. This causes

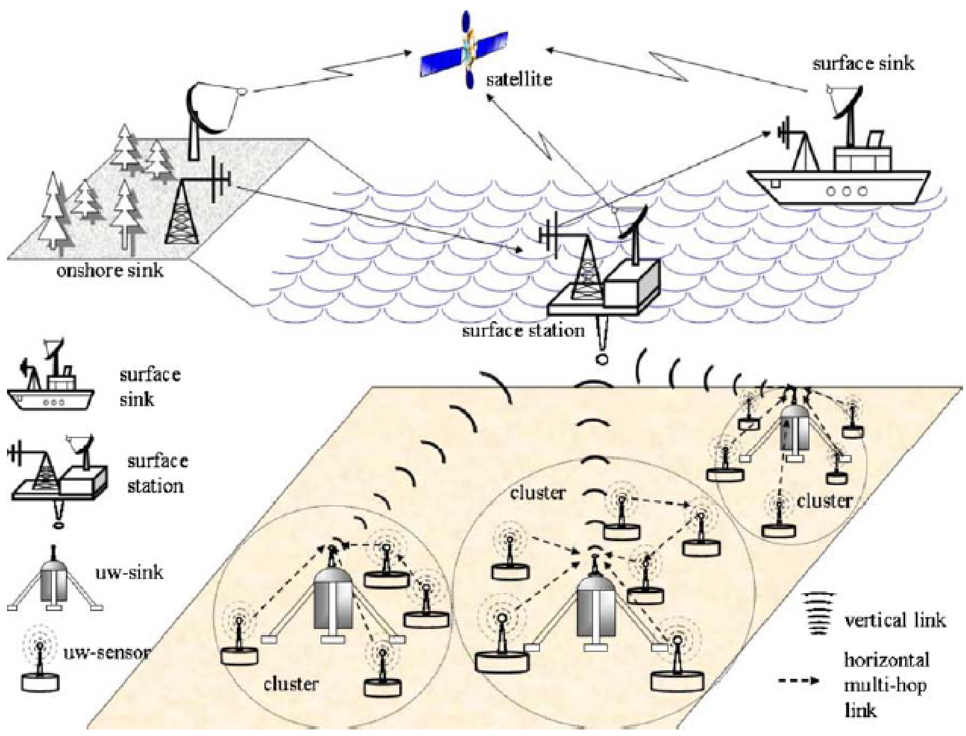

Figure 2.2: Architecture for underwater sensor networks

more energy savings and increases network capacity. However, this increases the complexity of the routing functionality. Every network device usually takes part in a collaborative process. Their key responsibility is to diffuse topology information such that efficient and loop free routing decisions can take place at each intermediate node. This can be achieved by the mechanism which consists of signaling and computation. From above discussion we can conclude that, energy and capacity are precious resources in underwater environments. The essential goal in UW-ASNs is to deliver event features by exploiting multi-hop paths and minimizing the signaling overhead necessary to construct underwater paths at the same time.

2.5 Basic Characteristics of Acoustic Communications

In order to state the challenges posed by the underwater channels for underwater sensor networking, the factors that influence acoustic communications are analyzed here. These include:

1. **High delay and delay variance:** In the UW-A channel the propagation speed is five orders of magnitude lower than in the radio channel. This large propagation delay (0.67 s=km) can reduce the throughput of the system considerably. For designing an efficient protocol, the very high delay variance is even more harmful. Because, it prevents from accurately estimating the round trip time (RTT) which is the key measurement for many common communication protocols.

2. **Path loss:** Water depth plays a major role in determining the attenuation which is mainly provoked by absorption due to conversion of acoustic energy into heat, which increases with distance and frequency. Moreover, it may occurred by scattering and reverberation (on rough ocean surface and bottom), refraction, and dispersion (due to the displacement of the reflection point caused by wind on the surface).

3. **Geometric Spreading:** Geometric Spreading increases with the propagation distance. It is independent of frequency. This refers to the spreading of sound

energy by cause of the expansion of the wavefronts.

4. **Noise:** Man made different types of noise. This is mainly caused by machinery noise produced from pumps, reduction gears, power plants and shipping activity, etc. Ambient noise is connected to hydrodynamics (movement of water including tides, currents, storms, wind, rain, etc.), seismic and biological phenomena.

5. **Multi-path:** Multi-path propagation generates Inter-Symbol Interference (ISI) may cause for severe degradation of the acoustic communication signal.

   The multi-path geometry depends on the link configuration. Vertical channels are characterized by little time dispersion. In fact, horizontal channels may have extremely long multi-path spreads, whose value depend on the water depth.

6. **Doppler spread:** The Doppler frequency spread can be significant in UWA channels [26]. This causes a deterioration in the performance of digital communications. Transmissions at a high data rate cause many adjacent symbols to interfere at the receiver, requiring sophisticated signal processing to deal with the generated ISI.

The chemical physical properties of the water medium such as temperature, salinity and density and spatio-temporal variations are the cause of the above mentioned factors. These variations, together with the wave guide nature of the channel, cause the acoustic channel to be temporally and spatially variable. Specifically, in both deep and shallow water, the horizontal channel is by far more rapidly varying than the vertical channel.

2.6 Features of the Underwater Acoustic Environments

For designing of MAC protocol compared to that of terrestrial networks, the underwater acoustic environment poses more severe circumstances [2,22,27].

1. **High and Variable Propagation Delay:** The spread speed of sound is about 1500m/s in underwater[28]. Consequently, the engendering delay in submerged is five requests of size higher than that of radio recurrence (RF) earthly channels over air. Besides, the engendering delay in submerged is very factor that relies upon temperature, saltiness and profundity of water. Thus, engendering deferral is immaterial for short range RF, though it is a basic for submerged interchanges. This causes genuine ramifications on the plan of MAC conventions.

2. **Limited Bandwidth and Data Rate:** The available acoustic bandwidth depends on the transmission distance due to high environmental noise at low medium frequencies. This can be lower than 1 kHz or high-control ingestion at high frequencies or can be more prominent than 50 kHz [26]. Just a couple of kHz might be accessible at many kilometers, while several kHz will be accessible at a couple of kilometers. Acoustic modems by and large work at the frequencies from simply a couple of Hz to many kHz. In this way, the information rate for submerged acoustic sensors can barely surpass 100 kbps. Contrasted and the transmission capacity in the request of a few hundred MHz offered by RF radios, the restricted data transfer capacity of acoustic channels needs concerned plan of coding plans and MAC conventions utilized in UWSNs.

3. **Noise:** Condition clamors comprise of man-made commotion and surrounding commotion. Man-made commotion for the most part alludes to hardware clamor like siphons while normal commotion alludes to seismic and natural marvels can cause encompassing commotion.

4. **Energy Consumption:** In sensor nodes batteries are energy constrained and cannot be recharged easily. Additionally, the acoustic handsets submerged have transmission controls in the request of size higher than that of the earthbound gadgets with a higher proportion of transmit to get control, so the conventions which use the acoustic radio viably turned out to be considerably more significant in UWSNs [29].

5. **High Bit Error Rates:** Due to multi-path fading, the underwater channel is

severely impaired. Multi-path propagation is accountable for severe degradation of the acoustic communication signals as it generates Inter Symbol Interference (ISI). Higher value of ISI may cause in higher bit error rates. Shadow zones and temporary losses of connectivity can be experienced in addition to the high bit error rates. Long paths and the frequency-dependent attenuation can cause “Shadow zone”. It shows almost no acoustic signal existing in it. Therefore, to design a MAC protocol great challenge is to provide certain reliability and maintain connectivity in such a harsh propagation conditions. The application of MAC protocols used for UWSNs will lead to inefficient results for these characteristics. Finally to develop MAC protocols suitable for underwater acoustic communications, it is necessary to take all the characteristics into account.

2.7 Challenges to the Design of MAC Protocols for UWSNs

The difficulties which must be engaged in the structure of UWSNs MAC conventions are clarified in this section[27]. Considering a MAC convention is a noteworthy test for the organization of UWSNs. An ideal submerged MAC convention ought to think about higher system throughput, and lower vitality utilization, assessing the harsh qualities of the submerged acoustic environment[2].

1. **Network Topology and Deployment in UWSNs:** In useful, the presentation of any MAC conventions for UWSNs is colossally dependable on the sending of submerged hubs which could be inadequate or thick. For the reason of the sensors hubs can screen just as impart at long separation because of the accessibility of long range acoustic modems, occasion readings of inadequately conveyed hubs would be amazingly uncorrelated.

2. **Synchronization:** The MAC conventions, for example, the obligation cycling approach work commonly dependent on the time synchronization of the hubs. Along these lines, synchronization is a basic test in the structure of MAC conventions. On the off chance that synchronization can not happen precisely,

the obligation cycling approach can't guarantee successful activity of sensor arranges by taking care of time vulnerability between sensor hubs. Since, the engendering deferral is a lot higher and changes every now and then.

3. **Hidden Node and Exposed Node Problem:** The issues of shrouded hubs and uncovered hubs emerge all the more especially in dispute based impact evasion MAC conventions. Shrouded hub circumstance takes places when one hub can't detect at least one hubs that can meddle with its transmission. In addition, when a station postpones transmission in view of another caught transmission that would not slam into it, an uncovered hub shows up. There will be crash and the hubs need to continue endeavoring for effective transmission for shrouded hub issue.

4. **High Delay Associated in Handshaking:** The customary handshaking plans need time and vitality to trade control data. In this manner, can decrease the impact of shrouded terminal and uncovered terminal. The a large portion of the correspondence time is required in light of trading of control data. Consequently, the hubs possess very little energy for the payload conveyance. The channel use rate is extremely low. The enormous test to the plan of proficient handshaking conventions is high proliferation delay in submerged condition.

5. **Power Waste in Collision:** In underwater environment a node consumes more power on transmission than on reception. More specifically, the ratio of power required for reception to transmission is typically 1/125 [30]. Moreover, frequently appear of collisions makes the ratio becomes worse due to the lack of an appropriate collision avoidance mechanism. Therefore, a MAC protocol should be designed such a way that it can avoid or minimize collisions.

6. **Near-Far Effect:** When the signals received by a receiver from a sender near the receiver is stronger than the signals received from another sender located farther then the near-far effect happens. The transmission power should be selected at the transmitter such a manner that the signals transmitted from the transmitter to the intended receiver should be correctly received with the desired SNR which is neither lower nor higher than the required SNR. In

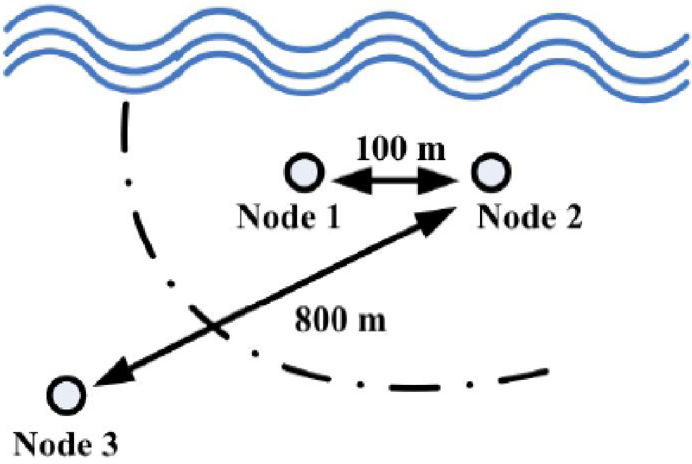

Figure 2.3: Near-Fear Problem

Figure 2.4 [31] the scenario of this problem is explained. From figure, we can see that nodes 1 and 3 can transmit simultaneously without causing collisions as they are far away. Here, as a result of high level of noise produced by the signals coming from node 1, at node 2, the SNR level of the signals originated from node 1 is higher than that from node 3. For this reason, node 2 can receive both signals but it cannot decode the messages from node 3. So, node 1 is unintentionally screening the transmissions from node 3.

7. **Centralized Networking:** In UWSNs centralized solutions are not a suitable solution over an acoustic channel. The communication between nodes happens through a central station in a centralized network scenario. The presence of a single failure point is the major disadvantage of this configuration. Furthermore, the network cannot cover large areas due to the limited range of a single modem [32].

2.8 Hidden-Node Problem in UWSNs

By means of exchanging RTS/CTS control packets, handshake-based protocols normally try to reserve the channel which are probably overheard by neighbors. Then, the neighbors are informed that the channel will be reserved. Therefore, they remain in the sleep mode as far as the occupied channel is released by stopping any transmissions. Thus they can avoid any possible collisions caused by neighboring hidden nodes.

As a result of long propagation delay, a new type of hidden-node problem is introduced yet in the underwater acoustic channel. Figure 2.5 illustrates the hidden node problem. Here, nodes A and D are the neighbor nodes. They may identify a channel reservation too late by overhearing the RTS or CTS after completing the transmission of their control packets, P1 and P2. This causes the early departure of packets without observing channel reservation. This may result collisions at the sender node B and receiver node C, which is indicated by the solid arrows. Nodes A and D are hidden from nodes B and C in this example. In a terrestrial radio channel, a hidden node is located beyond the signal's coverage; so its existence is not recognized. On the contrary, due to the long propagation delay, a hidden node problem may also appear even when it is located within the region covered in an underwater acoustic channel.

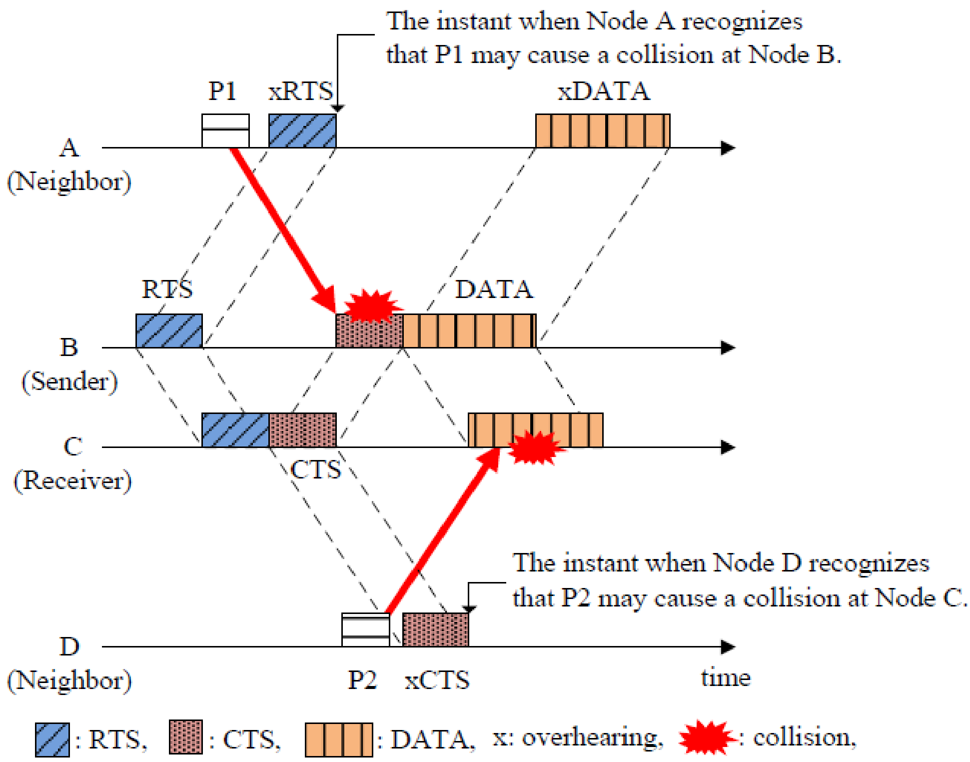

Figure 2.4: Hidden-node problem in UWSNs

2.9 Space-Time Uncertainty

Space-Time Uncertainty problem is highlighted in Figure 2.5. Here, a collision that occurs in RF-based terrestrial WSNs where the propagation delay is negligible is explained. The y-axis denotes the distance between nodes. If node A and C are transmitting packets, the packets may collide at destination node B. This collisions can be refrained by scheduling such a manner that the duration of the transmission time do not overlap. Therefore, only the transmission time uncertainty should be acknowledged. Additionally, the long propagation delay of the acoustic signal makes it more complex to avoid any collisions in under water environment. Therefore, we have to consider not only the transmission time, but also the distance between nodes. From Figure 2.7(b), we see that, two packets transmitted from Nodes A and C at different times collide at node B. This type of two-dimensional uncertainty in determining a collision at the receiver is named as space-time uncertainty [33].

2.10 Contention-free MAC protocols

Pioneer research studies focused on contention-free MAC protocols for UWSNs. The contention-free MAC protocols and their variations are studied in this section. Generally, three major multiple access techniques FDMA, TDMA, and CDMA are used [2].

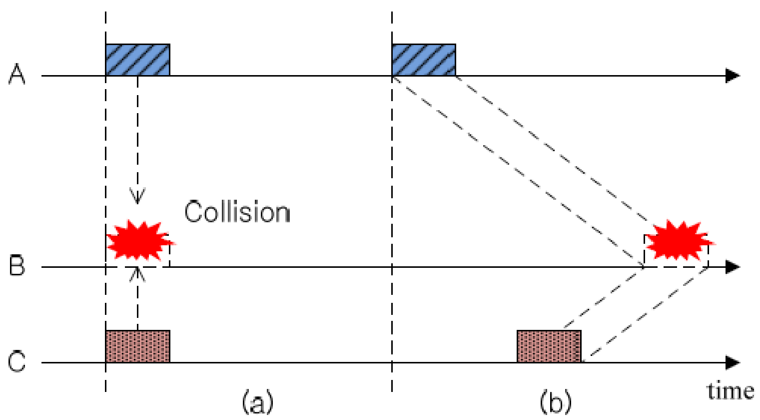

Figure 2.5: Space-time uncertainty a) terrestrial RF channel b) underwater acoustic channel

2.10.1 Frequency Division Multiple Access (FDMA)

In FDMA, the accessible recurrence band is partitioned into sub groups and each sub band is appointed to an individual client. In this manner, the channel is utilized distinctly by the client until it is discharged. The data transfer capacity of the aggregate of the FDMA channels is littler than the lucidness transfer speed of unique transmission channel. In this manner, the basic FDMA various access procedure isn't reasonable for UWSNs, as the restricted transmission capacity of submerged acoustic channels and the helplessness of constrained band frameworks to blurring and multi way.

2.10.2 Time Division Multiple Access (TDMA)

TDMA separates a period interim, called a casing, into schedule vacancies which are allocated to an individual client. Schedule openings and overhead bits are joined into edges. Besides, by including gatekeeper times crashes of bundles from adjoining vacancies are anticipated [34]. Accordingly, TDMA is increasingly basic and adaptable and better numerous entrance system connected to UWSNs. The watchman timeframes need be intended to isolate various channels for huge proliferation deferral and postpone change over the acoustic channels. In this way, it can limit the likelihood of crashes in information transmissions, which can prompt lower channel usages [35]. Moreover, the usage of an exact synchronization with a typical planning reference is required for TDMA which is especially extreme because of the variable postponement [36].

FDMA medium access has restricted transmission capacity and recurrence selectivity on the acoustic channels. In this way, TDMA medium access system turns into the real possibility for the submerged acoustic interchanges for beating the inalienable wastefulness. Different sorts of conflict free MAC conventions dependent on TDMA various access strategy have been created to control the medium access as of late. They center around defeating the lacking of the TDMA medium access strategy, for example, mistaken synchronization and low channel use. The plan difficulties of synchronization and high postponement related are for the most part looked by the TDMA-based conventions.

The amazed TDMA Underwater MAC Protocol (STUMP) [36] enables hubs to utilize basic or more vitality proficient synchronization plans. In this manner, it doesn't require tight hub synchronization to accomplish high channel use. Four potential clashes and the proliferation deferral have made the booking to be obliged in STUMP convention.

2.10.3 Code Division Multiple Access (CDMA)

Different clients are permitted to work at the same time over the whole recurrence band by CDMA. CDMA can recognize signals from various clients with the assistance of pseudo-commotion (PN) codes which are utilized for spreading the client messages [32]. Accordingly, the recipient can channel clamor by the spreading-code to pick up the right sign. CDMA does not require synchronization and turns into the promising medium access strategy. Be that as it may, the CDMA method experiences close far issue, which is the significant structure challenge for the MAC conventions. Consequently, the improvement of dispute free CDMA-based MAC convention is not many. A power control calculation is utilized to deal with the decrease of the yield power dimension of every hub such a way, that it can manage the close far issue.

2.11 Contention-based MAC protocols

Misusing the full data transfer capacity of the correspondence channel is the fundamental focal point of the greater part of the dispute based MAC conventions while planning for UWSNs [37]. The hubs go after a common direct bringing about probabilistic coordination in the conflict based conventions. The Contention-based conventions can be grouped further into arbitrary access and handshaking conventions [2].

2.11.1 Random Access

There are commonly two methodologies ALOHA and Carrier Sense Multiple Access (CSMA) for irregular access plot. At whatever point a hub has information prepared for the conveyance, it essentially begins its transmission in the arbitrary access approaches. On the off chance that an information parcel touches base at a collector and it isn't accepting some other bundles and there is no other bundle coming in the period, at that point the beneficiary can get this parcel effectively. In this manner, different hubs share the transmission medium arbitrarily with no control with the assistance of the irregular access approaches. RCAMAC is one of arbitrary access plot where the whole transfer speed is shared by numerous stations which effectively endure different impacts.

2.11.1.1 ALOHA protocols

In ALOHA approach, there is no avoidance of impacts. Accordingly, it is the least difficult arbitrary access MAC convention to be effectively actualized. At the point when a hub has information prepared to send, it will send the information at its will. Hence, if two hubs transmit parcels in the meantime, a crash happens. A retransmission is required for this situation. The convention works as such.

In [38], creator displays a clarification of Slotted ALOHA conventions for UWSNs. A hub can't send its parcels whenever in the Slotted ALOHA convention. In this way, the hub needs to sit tight for the start of a schedule opening. Henceforth, the convention lessens the odds of crashes.

2.11.1.2 CSMA protocols

CSMA is a regular class of arbitrary access conventions. In CSMA, every hub needs to detect the channel for a specific timeframe before the channel get to. On the off chance that clients tune in to the channel before transmitting a parcel, at that point the rare assets of the channel can be used much better.

In [39], another class of CSMA-based MAC conventions named Tone-Lohi (T-Lohi) has been proposed to take care of the issue of room time vulnerability. Hubs fight to hold the correspondence direct to send information in T-Lohi convention.

2.11.2 Handshaking

The handshaking convention is another significant sort of the dispute based MAC convention. The convention is basically a gathering of the booking based conventions. A transmitter needs to catch the channel before sending any information is the center thought of the handshaking or the booking based plans. The handshaking

MAC conventions can be ordered into two classifications: the MAC convention with single channel and the MAC convention with various channels.

2.11.2.1 MAC protocols with single channel

By the MAC protocols with single channel, only one channel is utilized for data communication. Exchanging of the handshaking messages for capturing the channel will be executed before any transmission of payload over only one channel.

Slotted FAMA, MACA-U, MACA-MN, RIPT, DOTS, R-MAC, ROPA, SF-MAC are renowned handshaking-based MAC protocol which are described in [10,12, 16, 17, 40,42] respectively.

2.11.2.2 MAC protocols with multiple channels

The multiple channel protocols utilize more than one channel for communication dissimilar from single channel MAC protocols. By this protocol, the node with outgoing packets will sends a RTS message over the control channel. Furthermore, the RTS frame have to consist of the sender/receiver identifier, the available channel set and the packet length.

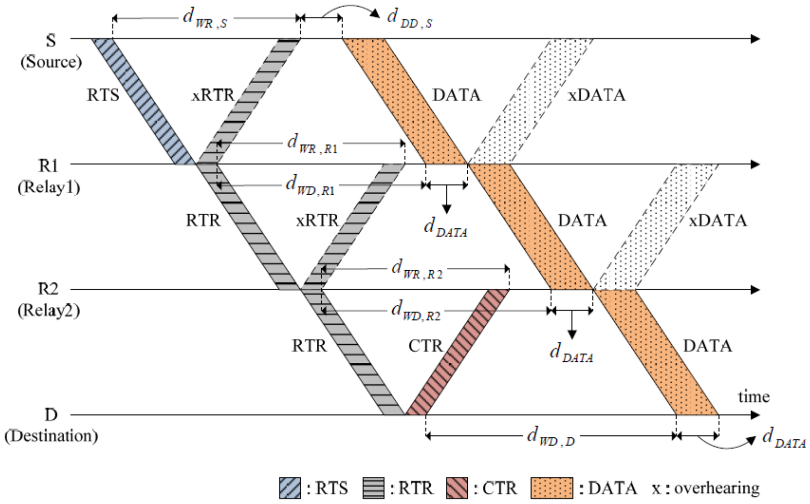

Figure 2.6: Operation of CMRT protocol

2.12 Cascading Multi-Hop Reservation

The cascading multi-hop reservation and transmission (CMRT), holds the multi-jump channels without a moment's delay with the assistance of falling reservation control parcels. Here, hand-off hubs between a source and a goal can begin hand-shaking ahead of time for the following jump handing-off before handshaking for the past hub is finished. The convention conveys the information parcels in a similar way until they achieve the goal hub ceaselessly at middle of the road hubs. Moreover, the convention receives a parcel train method[12] by sending numerous information bundles together with just a single handshaking signal, in this manner improves channel use,

CMRT assumes that every node knows the inter-nodal distance to its neighbors within a one-hop range and has the routing table to facilitate multi-hop relay [41]. A node shifts between six different states such as *Idle*, *Wait_Resp* (Wait for response), *Delay_Data* (Delay Data transmission), *Wait_Data* (Wait for Data reception), *Data_Rx* (Data Reception) and *Silence*.

2.13 Summary

This chapter provides a brief overview of the communication architecture of underwater sensor networks, role of MAC layer in network architecture, different types of multiple access techniques in MAC layer, problems that may encounter during MAC protocol design, different classes of MAC protocols and the issues that should be considered during MAC protocol design. Furthermore, the challenges of different types of under water sensor network MAC protocols that should be considered during MAC protocol design are also depicted in this chapter as well.

Chapter 3

A Bidirectional Multi-Flow Mac Protocol

This chapter presents a new energy efficient, low latency medium access control protocol, Bidirectional Multi-flow MAC protocol (BMF-MAC), for UW-ASNs. This protocol is based on handshaking-based MAC protocol to handle variable traffic load patterns for UW-ASNs. The proposed BMF-MAC protocol is aimed at improving the performance of existing CMRT protocol [4]. At first, the operation cycles of proposed MAC protocol along with its control frame structure is illustrated. Multi-hop multi-flow data forwarding with reverse packet method is outlined here as well. Transition diagram and algorithm for data transmission technique for both sender and relay node are also laid outed. Finally, in order to evaluate the performance of the proposed MAC protocol, mathematical model is derived which includes energy consumption, latency, throughput and frame error probability.

3.1 System Description

In this theory, we have proposed a multi-stream MAC convention in static submerged sensor systems. We think about that each hub is furnished with an omni-directional half-duplex acoustic modem. It is expected that hubs gauge the engendering post-pone utilizing data got from their two-bounce neighbors. While the system is in-stated, the separation between hubs are determined with the assistance of control parcels that measure round-trip time (RTT) or by data sharing between neighboring nodes[4]. Additionally, we consider all hubs have steering tables which help to hand-off through multi-bounce hubs.

3.2 Network Model

In our proposed protocol flow is set in this manner that, multiple flows can be constructed from single node, thus a node can transmit multiple packets over multiple flows. Furthermore, a sender can sends different packets to different multiple destination nodes. From intermediate node of the flow may add additional final destinations. The network model is considered with multiple sinks. The network model is illustrated in Figure 3.3.

3.3 Definition of States

In BMF-MAC protocol, a node shifts between fourteen different states. Six states are defined in the same way as CMRT protocol. Four new states are introduced to handle data transmission over reverse flow direction. Figure 3.4 illustrates the states of the protocol.

The state where a sender hangs tight for a reaction to a solicitation control bundle (e.g., RTS) from a beneficiary is called $Wait\_Resp$ state. Subsequent to transmitting a solicitation control parcel, the sender remains in the $Wait\_Resp$ state until accepting a reaction control bundle. Inside the length of $Wait\_Resp$ state, if the sender does not get a reaction control parcel, it will travel to the $Idle$ state.

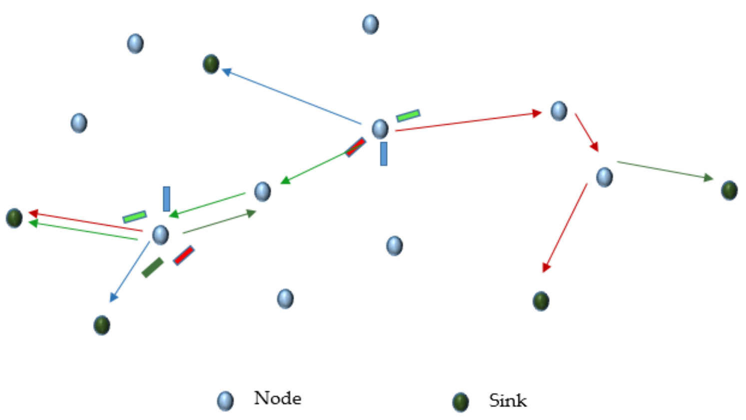

Figure 3.1: Network Model

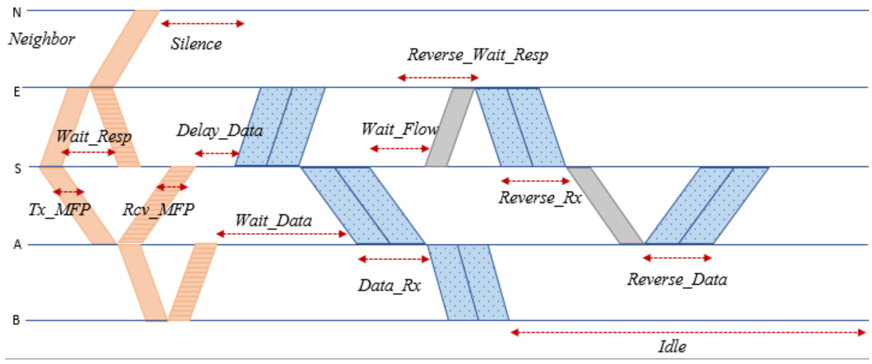

Figure 3.2: States of BMF-MAC protocol

The state where a sender defers information transmission to stay away from potential crashes brought about by the shrouded hubs is called *Delay_Data* state. Subsequent to getting a reaction control bundle from the beneficiary, the sender enters the *Delay_Data* state and stays there until it begins transmitting information parcels.

The length of the *Delay_Data* state is intricately determined, and the computation system is displayed in Section 3.7.

The state where a beneficiary sits tight for information parcels from a sender is called *Wait_Data* state. Subsequent to transmitting a reaction control parcel, the recipient enters the *Wait_Data* state straightforwardly and remains there until it begins getting information bundles.

A collector gets information bundles in *Data_Rx* state.

The state where neighbors who caught the trading of control parcels for channel reservation stay quiet is named *Silence* state. As the hub do nothing they don't cause crashes.

Neighbors enter the Silence state in the wake of catching the control bundles associated with other hubs' channel reservation until the channel turns out to be free of reservation. The Silence state guarantees that any transmissions from neighbors touch base after information gathering is finished at a collector.

The *Idle* state is a state where a node has no activity to do.

3.4 Protocol Description

Figure 3.5 and 3.6 illustrate the topology and the operation of the BMF protocol correspondingly. In Figure 3.5, it is expected that hub S mean a sender. Assume hub S has bunch parcels for goal hubs C and G. Here, hand-off hubs E and F stay between source S and goal G in one stream bearing. Then again, between source S and goal C hand-off hubs An and B stay in other stream bearing. In this manner, hub S sends bundles to goal hub C through hub An, and B and goal hub G through E, and F individually.

Handing-off procedure of multi-stream is built up when the source hub S begins transmitting MFP, a recently presented control bundle in BMF convention, to transfer hubs E and An all the while. In the wake of transmitting MFP, sender S enters the $Wait\_Resp$ state like CMRT convention [4]. Hub S begins the handshake by transmitting MFP to hub E and hub A with the primary goal address set to hub E, and the second goal address set to hub A. The planning of addresses relies upon hub separations; short inaccessible hub will be organized first.

As first location has given to hub E, it has the principal planning need for both standard and invert stream information transmissions. On the off chance that hub S prior got the affirmation MFP from its next bounce E, S transfers the information parcel to E after the time interim of *Delay_Data* ($D^{f1}_{DD,S}$) like [4]. Here, $D^{f1}_{DD,S}$ implies the postpone time of sender hub S from transmitting information for first stream. The hand-off hub E can transmit a train of information parcels to the following hand-off hub F consistently without having whenever length between

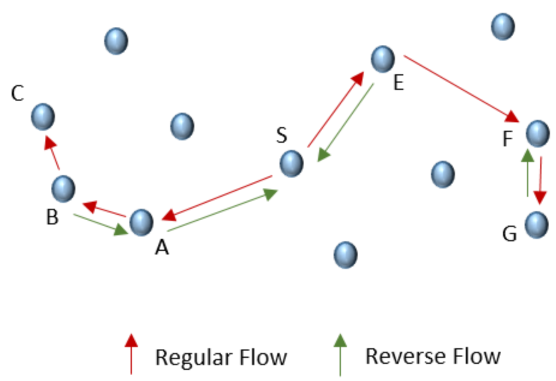

Figure 3.3: Topology

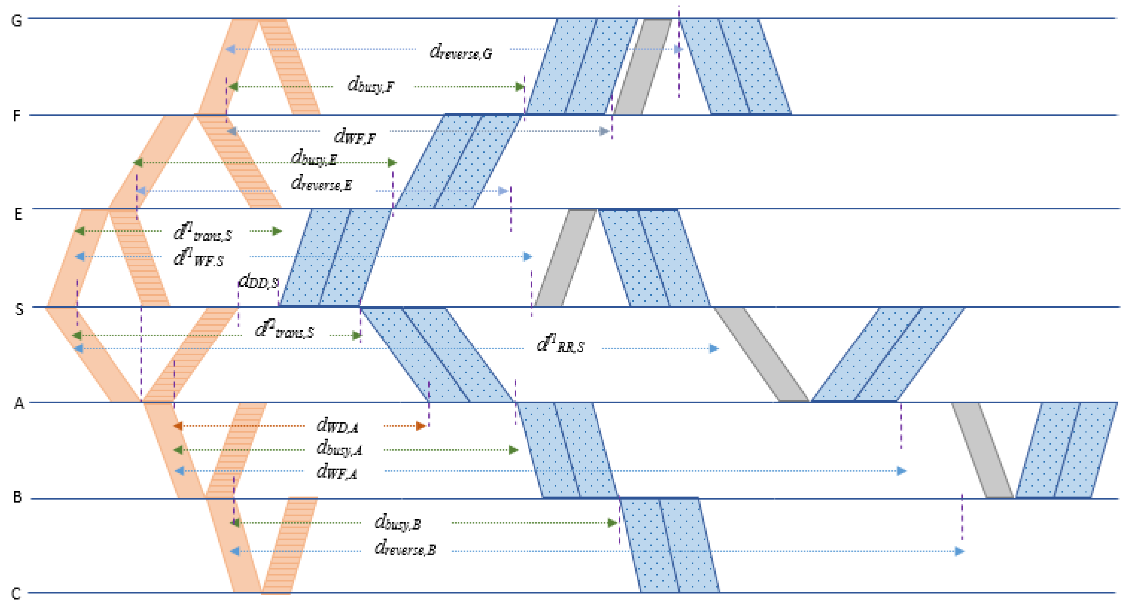

Figure 3.4: Operation of the bidirectional multi-flow MAC protocol

bundles. Correspondingly, hub F additionally advances the train of information bundles without interim for the reason that the multi-bounce channels are saved coordinated toward the goal hubs.

To avoid potential crashes from information transmission over different streams, source hub S delays from transmitting information for *Delay_Data* ($D^{f1}_{DD,S} + d_{data}$). The information conveying procedure of the second stream fills in as a similar path as the first. This information parcel sending procedure proceeds at each bounce until the last goal C is come to. In this manner, information transferring procedure is particularly similar to a pipeline procedure. The information from two unique steams can be conveyed all the while in our proposed convention.

3.4.1 Transmission of Data Adopting the Reverse Packet Method

Assume, for the main stream from S to G, there are turn around parcels from hub E to S and hub G to F. Consequently, while transmitting MFP parcel from S to E, S sets its turn around banner to 1. In addition, F transmits MFP in a similar way to hub G. After the transmission of information parcels from hub S to E and S to A, hub S enters in *Wait_Flow* state and transmits a CTS to hub E and E promptly transmits information bundle to S. Moreover, as there is no transmission

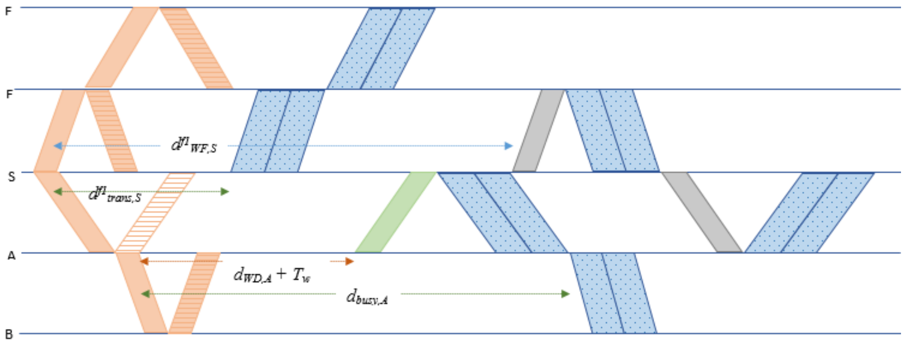

Figure 3.5: Scenario 1: Sender misses a confirmation

going on one bounce separation of hub F, after culmination of forward transmission of information parcels from hubs F to G, F sends a CTS to G and G sends invert information bundle to F in a flash.

Algorithm 1 Reverse Waiting Time Calculation

if $reverse\_flag = 0$ in requested MFP of R_{i-1} **then**
  $d_{reverse}[R_i] = d_{WF}[R_{i-1}] + T_{CTS} + propagationdelay$
else
  $d_{reverse}[R_i] = d_{WF}[R_{i-1}] + 2T_{CTS} + 2\ propagationdelay + d_{data}$
end if

Envision that hub A has bunch parcels for goal hub S and hub B has clump bundles for goal hub A. As hub An is set as second goal, after end of normal and turn around transmission of hub E, hub A begins its switch stream information bundle transmission. Hub S transmits a CTS to hub A. also, A promptly transmits information parcel to S. The information sending process from hub B to A performs similarly too. The switch holding up time figuring has been depicted in Algorithm 1.

3.4.2 Transmission of Data Adopting Request Packet Method

The Algorithm 2 and 3 explain the retry technique of handling any missing MFP packets.

Scenario 1: Sender misses an affirmation: Suppose in Figure 3.7, the sender hub S does not get affirmation MFP parcel to its mentioned MFP of hub A. Let, $d_{WD,A}$ holding up span of hub An in $Wait\_Data$ state. After $d_{WD,A} + T_w$ (T_w is

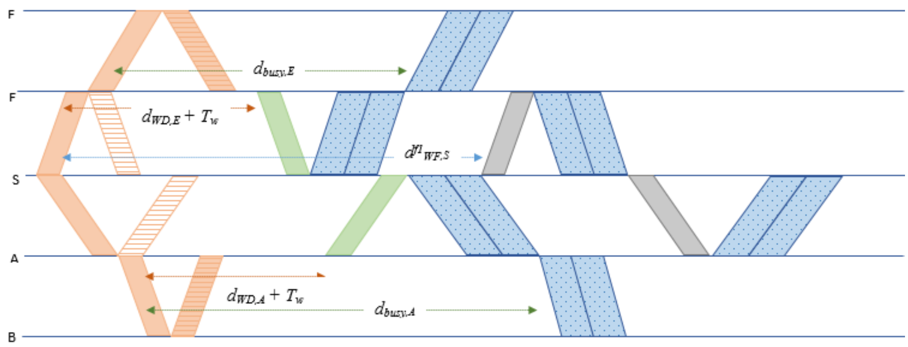

Figure 3.6: Scenario 2: Sender misses a confirmation

a short holding up time) span of time when recipient A does not get information from sender S, hub An accept that its affirmation MFP bundle does not gotten by S. Along these lines, hub A sends RP bundle and the sender hub S starts sending information parcels for second stream to hub A.

Scenario 2: Sender misses all confirmation: In the second situation which is portrayed in figure 3.8 the sender hub S does not get affirmation to its solicitation of the two hubs E and A. After $d_{WD,E} + T_w$ term of time when collector E does not get information from sender S, hub E sends RP parcel and the sender hub S promptly begins sending information bundles for first stream to hub E. Similarly, $d_{WD,A} + T_w$ period later when collector A does not get information bundle from hub S, hub A sends RP parcel and the sender hub S begins sending information parcels for second stream to hub An immediately.

Scenario 3: Intermediate node misses a confirmation: Accept that because of bundle impact, the transfer hub E does not get affirmation MFP parcel of hub F. At the point when hand-off hub F does not get information bundle from hand-off hub E, hub E transmits RP parcel and the hub E begins transferring information parcels to hub F right away.

Scenario 4: Immediate destination node misses a confirmation: Assume, the prompt goal hubs B does not get affirmation to its solicitation of goal hub C. After $d_{WD,C} + T_w$ term of time when hub C does not get information from hand-off B, hub C sends RP bundle and hub B promptly begins transmitting information to goal C.

Scenario 5: At last, in the fifth situation where the transfer hub neglects to get the mentioned MFP bundle while the sender S has sent MFP to the hand-off. Henceforth, the hand-off does not wake up, and the sender sits tight for gathering

Algorithm 2 Sender Missing MFP

for i numbers of flows **do**
  if $state = Delay\_Data$ and all MFP's are missing **then**
    Step 3: Go to state $Wait\_Retry$
      Wait time $d_{DD,S} + Tw$ for receiving RF
      Go to state Tx_Data
      Update time $d^{f}_{trans,S}$ and Send data
      if $i < f$ **then**
        Go to step 3
      else Go to step 1
      end if
  else if $state = Tx\_Data$ and any missing MFP find then
    for i number missing MFP **do**
      Go to state $Wait\_Retry$
      Wait for $d^{i-1}_{trans,S} + propagation\_delay + T_w$ time for RF
      if $RF = 1$ **then**
        Send data
      end if
    end for
  end if
end for

of RP parcel from the hand-off. As sender does not get RP parcel, it will surmise that its solicitation is lost and after $Wait\_Retry$ state sender will send MFP bundle once more.

Algorithm 3 Relay Missing MFP

---

for i numbers of flows **do**
    if $T = d_{WD,R_i} + T_w$ and no data request **then**
        Go to state Tx_Retry and transmit CTS
        if $T = d_{WD,R_i} + T_w + T_{CTS} + propagation\_delay$ **then**
            Receive data
            Update time d_{WF,R_i} and $d_{reverse,R_i}$
        else if ($State = Tx\_data$ and no RMFP is received) **then**
            Go to sate $Wait\_Retry$
            Receive RP and send data to R_{i+1}
            Update time d_{WF,R_i} and $d_{reverse,R_i}$
            if ($Reverse\_flag = 1$ in RP) **then**
                Go to **step 1**
            else Go to state $Idle$
            end if
        end if
    end if
end for

3.5 State Transition Diagram for Sender Node

The state transition diagram of a sender in our proposed MAC protocol BMF-MAC is interpreted in Figure 3.9. This diagram depicted the behavior of a sender how it transmits multi-flow multi-hop packets. Let us starts the transition from the $Idle$ state. When a sender has no activity to do, it remains in $Idle$ state. In $Idle$ state, if a sender generates new packets and channel is idle, it moves to the Tx_MFP state.

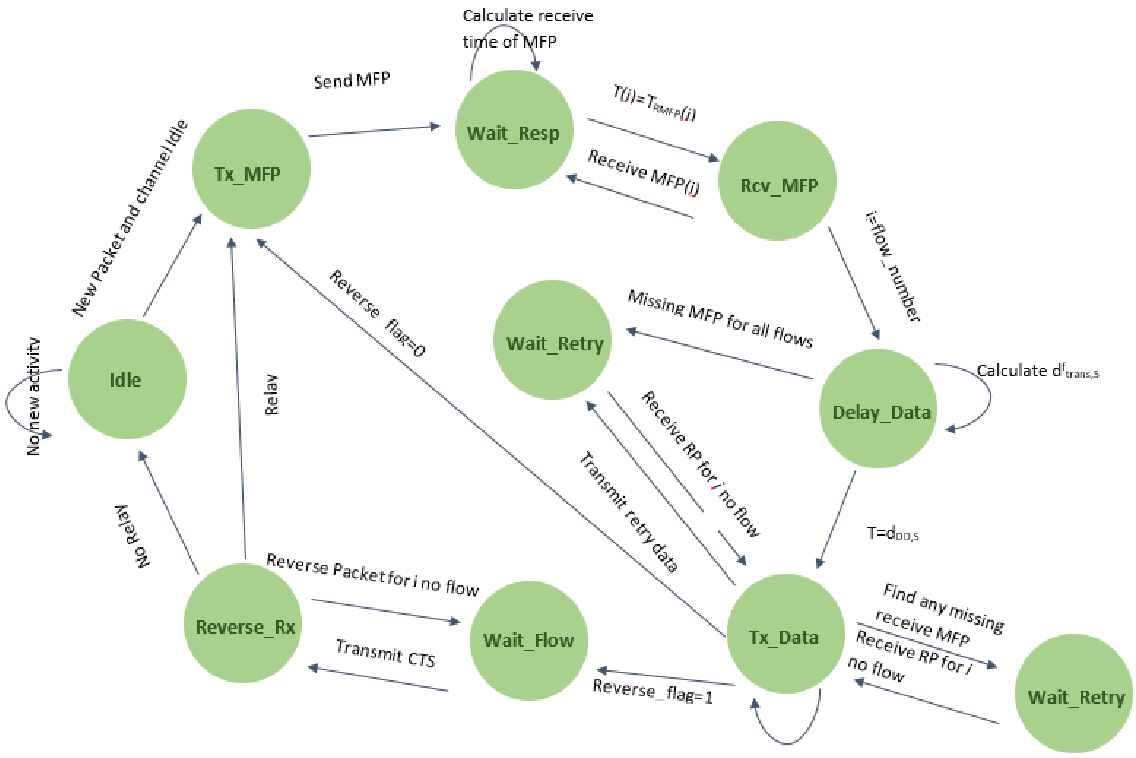

Figure 3.7: State transition diagram of a sender of the bidirectional multi-flow MAC protocol

3.5.0.1 Reverse data transmission

In case 1) In the event that the sender does not miss MFP for any streams and $reverse\_flag$ is set, the sender hangs tight for $d^i_{WF,S}$ (sit tight length for transfer I in $Wait\_Flow$ state) time in the state $Wait\_Flow$ for staying away from crash. At that point after this length of time, the sender transmits CTS bundle and moves to $Reverse\_Rx$ state.

3.5.0.2 Retry transmission

In case 2) On the off chance that the sender misses reaction MFP for any stream, the sender hangs tight for time T_w in $Wait\_Retry$ state. In the wake of getting RP bundle for specific MFP, sender hub at that point enters in Tx_Data state for accepting information from the hand-off hub. On the off chance that more than one reaction MFP is missed, at that point hub moves between this two states Tx_Data and $Wait\_Retry$. At that point, if hub has switch information to get it goes to $Wait\_Flow$ state, transmits CTS and moves to $Reverse\_Rx$ state.

Algorithm 4 Sender Transmission Process over reverse flow

if $state = Wait\_Flow$
    for i number of flows **do**
        if $T = d^{i}_{trans,S} + propagation\_delay$ **then**
        Step 2: Send CTS to R(1) relay of i flow
            Go to state $Reverse\_Rx$
            if $T = d^{i}_{WF,S} + propagation\_delay$ **then**
                Receive reverse data from R(1)
            if $reverse\_flag = 1$ in confirm MFP for $i + 1$ number flow
                Go to step 2
            else Go to state $Idle$
            end if
        end if
    end for
end if

3.5.0.3 *Reverse_Rx* state

In case 3) In state $Reverse\_Rx$ the hub gets information over turn around stream bearing. In the event that the sender hub has no information to hand-off, it goes to state $Idle$; generally, the sender goes to state Tx_MRP. Calculation 4 portrays the switch stream transmission procedure of sender hub S.

3.5.1 *Data_Rx* state

From state $Data\_Rx$, transfer can move to four distinct states as per the accompanying cases. Case 1) in the event that that the hand-off hub gets information and finds affirm MFP, it moves to Tx_Data state. Case 2) If the transfer gets information however misses affirm MFP, it moves to $Wait\_Retry$ state. Case 3) If the hand-off gets information and $reverse\_flag = 1$, the hub moves to $Reverse\_Wait\_Resp$ state. Case 4) Finally, if the hand-off gets information and transfer hub is the last hub over the stream and $reverse\_flag = 0$, the hub moves to $Idle$ state.

On the off chance that 1) After accepting information parcels, the hand-off begins

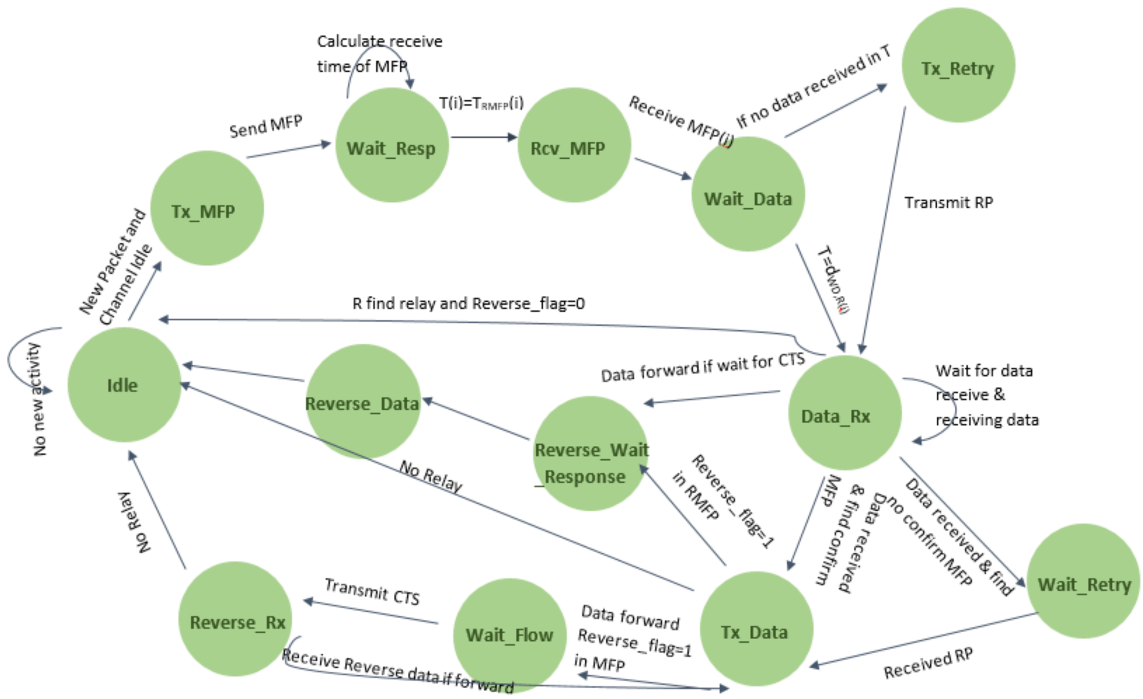

Figure 3.8: State transition diagram of a relay of the bidirectional multi-flow MAC protocol

transmission of information bundles to its next transfer hub in *Tx_Data* state.

On the off chance that 2) If the hub misses affirm MFP, it sits tight for accepting retry parcel RP in *Wait_Retry* state. In the wake of accepting RP from comparing transfer hub, the hub moves to the *Tx_Data* state for transmitting information parcel for that particular RP bundle.

3.5.2 *Tx_Data* state

A hub transmits information parcel to its next transfer hub in *Tx_Data* state. In *Tx_Data* state, three circumstances may happen: Case 1) in the event that that, the hand-off hub advances information and finds $reverse\_flag = 1$ in mentioned MFP, it moves to *Wait_Flow* state. Case 2) In other case, while the hub advances information and finds $reverse\_flag = 1$ in reacted MFP, it enters in *Reverse_Wait_Resp* state. Case 3) If hand-off has no information to transfer, it goes to *Idle* state.

In Case 1) A hub goes to *Wait_Flow* state from *Tx_Data* state when it needs to get turn around information parcel. The hand-off figures the time d_{WF,R_i} and hangs tight for d_{WD,R_i} time length for evading impact in *Wait_Flow* state. In the wake

Algorithm 5 Relay Transmission Process over reverse flow

```
if state = Tx_Data and final RMFP from R_{i+1} relay then
    if reverse_flag = 1 in confirm RMFP then
        Step 1: Calculate Reverse waiting time d_{Reverse,R_i}
        Go to state Reverse_Wait_Resp
        if T = d_{reverse,R_i} + T_{CTS} + propagation_delay then
            Receive CTS and go to state Reverse_Data
            Transmit reverse data and go to state Idle
    end if
    else if (Reverse_flag = 1 in MFP)
        Calculate flow waiting time d_{WF,R_i}
        Go to state Wait_Flow
        Transmit CTS and go to state Reverse_Rx
        if T = T_{WF,R_i} + T_{CTS} + propagation_delay then
            Receive reverse data and go to state Idle
        end if
    end if
end if
```

of sending CTS bundle to the interrelated hand-off hub, the hub moves to the state $Reverse\_Rx$ state.

In Case 2) At the point when the hand-off needs to send turn around information parcel, it moves to $Revese\_Wait\_Resp$ state from Tx_Data state. In this express, the hub ascertains the time $d_{Reverse,R_i}$ and hangs tight for $d_{WD,R_i} + T_{CTS}$ time span for keeping away from impact. In the wake of accepting reaction bundle CTS from the particular hand-off hub, the hub moves to $Reverse\_Data$ state. The hub transmits turn around information in $Reverse\_Data$ state. On the off chance that there is no transfer hub, the hand-off moves to the $Idle$ state. Calculation 5 clarifies the transmission procedure over turn around stream of transfer hubs.

3.6 Calculation of the Time Duration Parameters

Depending on the number of flows, the batch size of data, the number of bidirectional data packets, the busy duration should be computed.

Here we consider that τ_{max} is the maximum propagation delay between nodes. $T\_control$ is the common transmission time of all control packets. The busy duration of node S for first flow in Figure 3.6 is as follows

$$d^{f1}_{busy,S} = 2\tau_{max} + T_{control} + d^{f1}_{DD,S} \tag{3.1}$$

Assume d^{f1}_{data} and d^{f2}_{data} are the transmission time of batch data packets for flow one and two respectively. The waiting and busy duration of Node E is

$$d_{WD,E} = 2\tau_{max} + T_{control} \tag{3.2}$$

$$d_{busy,E} = d_{WD,E} + d^{f1}_{data} \tag{3.3}$$

Assume T_{data} is a single data packet transmission time and B_{SIZE} is the batch data size. That means, $d_{data} = T_{data}\ B_{SIZE}$. Therefore, the busy duration of Node F is given by:

$$\begin{aligned} d_{busy,F} &= (d_{busy,E} - T_{control}) + B_{size}T^{f1}_{data} \\ &= 2\tau_{max} + 2B_{size}T^{f1}_{data} \end{aligned} \tag{3.4}$$

Thus the busy duration of relay node R_i for first flow can be generalized as well.

$$d_{busy,R_i} = 2\tau_{max} + iB_{size}T_{data}^{f1} - (i-2)T_{control} \tag{3.5}$$

The busy duration of Node S for second flow in Figure 3.6 is as follows

$$d_{busy,S}^{f2} = d_{busy,S}^{f1} + d_{data}^{f1} \tag{3.6}$$

The waiting and busy duration of Node A is

$$d_{WD,A} = 2\tau_{max} + T_{control} + d_{data}^{f1} \tag{3.7}$$

$$d_{busy,A} = d_{WD,A} + d_{data}^{f2} \tag{3.8}$$

Like Node A, the waiting and busy duration of B is:

$$\begin{aligned} d_{busy,B} &= (d_{busy,A} - T_{control}) + B_{size}T_{data}^{f1} \\ &= (2\tau_{max} + T_{control} + d_{data}^{f1} - T_{control}) + B_{size}T_{data}^{f2} \end{aligned} \tag{3.9}$$

Imagine f is the total number of flows. Therefore, we can derive the busy duration of relay node R_i for second flow as well.

$$d_{busy,R_i} = 2\tau_{max} + d_{data}^{f1} + iB_{size}T_{data}^{f2} - (i-2)T_{control} \tag{3.10}$$

$$d_{busy,R_i} = 2\tau_{max} + (f-1)\, d_{data} + iB_{size}T_{data}^{f2} - (i-2)T_{control} \tag{3.11}$$

The waiting time for ongoing first flow of Node S in Figure 3.6 is given by:

$$d_{WF,S}^{f1} = d_{busy,S}^{f2} + d_{data}^{f2} \tag{3.12}$$

Assume T_{CTS} is the transmission time of a CTS packet. Hence, the delay time for reverse flow of node E for first flow is given by:

$$d_{reverse,E} = d_{WF,S}^{f1} + T_{CTS} \tag{3.13}$$

The waiting time of node F and delay time of node G is:

$$d_{WF,F} = d_{busy,F} + d_{data}^{f1} \tag{3.14}$$

$$d_{reverse,G} = d_{WF,F} + T_{CTS} \tag{3.15}$$

The delay time for reverse flow of node A for the second flow is:

$$d_{reverse,A} = d_{WF,S} + T_{CTS} \tag{3.16}$$

In the same way the waiting time of node A and delay time of node B is:

$$d_{WF,A} = d_{reverse,A} + d_{data}^{f2} \tag{3.17}$$

$$d_{reverse,B} = d_{WF,A} + T_{CTS} \tag{3.18}$$

The wait time of first flow and second flow for node S are accordingly stated below.

$$d_{WF,S}^{f1} = d_{busy,S} + f.d_{data} \tag{3.19}$$

$$d_{WF,S}^{f2} = d_{WF,S}^{f1} + T_{CTS} + d_{data}^{reverse} \tag{3.20}$$

Thus the generalized formula of wait time calculation for other than first flow is

$$d_{WF,S}^{f_n} = d_{WF,S}^{f_{n-1}} + T_{CTS} + d_{data}^{reverse} \tag{3.21}$$

If the node E has reverse data then the wait flow time is

$$d_{WF,E} = (d_{busy,S} - T_{control}) + f.d_{data} + T_{CTS} + d_{data}^{reverse} \tag{3.22}$$

When previous hop node has reverse data for transmission then the equation for first flow relay node R_i is

$$d_{WF,R_i} = (d_{busy,R_{i-1}} - T_{control}) + f.d_{data} + i.T_{CTS} + i.d_{data}^{reverse} \tag{3.23}$$

As in our example relay E does not have any reverse data thus the wait flow time of relay F is

$$d_{WF,F} = d_{busy,F} + d_{data} \tag{3.24}$$

Therefore, if previous hop relay does not have any data over reverse flow direction then the wait flow time can be generalized as

$$d_{WF,R_i} = d_{busy,R_{i-1}} + d_{data} \tag{3.25}$$

For the second flow, the wait time of node A is

$$d_{WF,A} = (d_{busy,S} - T_{control}) + f.d_{data} + 2T_{CTS} + 2d_{data}^{reverse} \tag{3.26}$$

More specifically, the generalized formula of wait flow for other than first flow is

$$d_{WF,R_i} = (d_{busy,R_{i-1}} - T_{control}) + f.d_{data} + f_n.T_{CTS} + f_n.d_{data}^{reverse} \tag{3.27}$$

3.7 Frame Error Probability

The bit error rate (BER) is the number of bit errors divided by the total number of transferred bits during a studied time interval. Here, p is the frame error probability, which is related to the bit error rate (BER) p_e. l is the data packet size (bits) and l_{oh} is the frame overhead size (bits). From [?] we can get frame error probability.

$$p = 1 - (1 - p_e)^{l+l_{oh}} \tag{3.28}$$

The probability of no error of frame transmission is p_c.

$$p_c = (1 - p_e)^{l+l_{oh}} \tag{3.29}$$

3.8 Throughput

The network throughput is defined as the total number of packets delivered at the sink node per time unit.

$$Throughput = (NumberofPacket.NumberofBitsPerPacket)/RequiredTime \tag{3.30}$$

Here, we consider two version of BMF-MAC. One is BMF-M which is a version of BMF protocol, where only multi-flow data transmission is considered. On the other hand, BMF-R contemplates multi-flow data transmission with reverse packet method. In our experiment control packet collision is not considered.

We assume that $T\_control$ denotes the common transmission time of one MFP frame and i is the number of packet to be transmitted. Then, to transmit single MFP frame it needs time

$$TimeforMFP = 2(T_{control} + \tau_{max}) \tag{3.31}$$

The duration to transmit a single data frame is (T_{data}+τ_{max}) and B_{SIZE} is the batch data size. That means, $d_{data} = T_{data}\ B_{SIZE}$. Then to transmit one batch data frame, it requires time:

$$TimeforDATA = (d_{data} + \tau_{max}) \tag{3.32}$$

$$TimeforDATA = (T_{data}.B_{SIZE} + \tau_{max}) \tag{3.33}$$

We assume that the required time to send packets to a relay node that is one hop away from the sender node will be

$$Time_1 = TimeforMFP + TimeForDATA \tag{3.34}$$

The required time to send packets from a node that is h multiple hops away from the sender node will be

$$Time_2 = h.TimeforMFP + h.TimeForDATA \tag{3.35}$$

Now, for i number of packets over f number of flows it needs time for BMF-M protocol:

$$Time_3 = (1 - p_e)^{l+l_{oh}}.i.Time_2 \tag{3.36}$$

For reverse packet it needs time

$$Time_4 = (1 - p_e)^{l+l_{oh}}.i.h.Time_1 \tag{3.37}$$

Hence, for BMF-M protocol, required time is

$$RequiredTime = Time_3 + Time_4 \tag{3.38}$$

On other hand, for BMF-R, to transmit packets in reverse direction it needs time

$$Time_5 = (1 - p_e)^{l+l_{oh}}.i.T_{CTS} + \tau_{max} + TimeforDATA \tag{3.39}$$

Therefore, for BMF-R, required time is

$$RequiredTime = Time_3 + Time_5.h \tag{3.40}$$

The $Time_3$, $Time_4$ and $Time_5$ can be calculated from equation (3.27), (3.28) and (3.30) respectively. Hence, placing the values of the above mentioned times into equation (3.29) and (3.31) RequiredTime can be measured for both version of BMF-MAC. Then, the throughput can be derived from the equation (3.21) using the measured RequiredTime.

3.9 Latency

Latency is an important design and performance characteristic of underwater sensor network. Latency is the end to end delay of a packet that is the amount of time it takes a packet to travel from source to destination. Latency measures the amount of time between the start of data transmission and its completion.

We assume that T_{contol} denotes the transmission time of one MFP frame, i is the number of packet to be transmitted. Then, in multi hop scenario, to transmit a single MFP frame, it needs $2.(T_{contol} + \tau_{max})$ time and a MFP have to wait ($T_{control}$ $+\tau_{max}$)time before transmitting. Therefore, total latency of a single packet to transmit will be

$$LatecyforMFP = 3.(T_{control} + \tau_{max}) \tag{3.41}$$

The duration to transmit a data frame is d_{data}. Then, to transmit a data frames, it requires (d_{data} $+\tau_{max}$) time and a data have to wait $(d_{WD,R_i} - 2.T_{contol} - 2\tau_{max})$ time before transmitting. Therefore, total latency of a single packet to transmit will be

$$LatencyforDATA = (d_{data} + \tau_{max}) + (d_{WD,R_i} - 2.T_{contol} - 2\tau_{max}) \tag{3.42}$$

The contention window size is CW. The latency to send packets from a sender node to h hop relay node in multi-hop scenario will be

$$Latency_1 = CW + d_{DD,S} + h.LatencyforMFP + h.LatencyforDATA \tag{3.43}$$

Now, for i number of packets to be transmitted in probability p_c, latency will be

$$Latency_2 = CW + d_{DD,S} + p_c.i.h.LatencyforMFP + p_c.i.h.LatencyforDATA \tag{3.44}$$

In the same way, for data transmission in reverse flow direction, latency of r number of packets will be

$$Latency_3 = CW + d_{DD,S} + p_c.r.h.LatencyforMFP + p_c.r.h.LatencyforDATA \tag{3.45}$$

Hence, for BMF-M protocol, total latency will be

$$Latency = Latency_2 + Latency_3 \tag{3.46}$$

On the other hand, for BMF-R protocol for reverse packets latency for control frame will be

$$Latency_4 = (T_{CTS} + \tau_{max}) + (d_{WF,R_i} - 2.T_{control} - 2\tau_{max}) \tag{3.47}$$

On the other hand, for BMF-R protocol for reverse packets latency for data frame will be

$$Latency_5 = (d_{data} + \tau_{max}) + (d_{Reverse,R_i} - 2.T_{control} - 2\tau_{max}) \tag{3.48}$$

Hence, for BMF-R protocol overall latency will be

$$Latency = Latency_2 + Latency_4 + Latency_5.h \tag{3.49}$$

The $Latency_2$, $Latency_3$, $Latency_4$ $Latency_5$ can be determined from equation (3.35), (3.36), (3.38), and (3.39) respectively. Therefore, inserting the values into equation (3.37) and (3.40) latency can be measured for both version of BMF-MAC protocol.

3.10 Energy Consumption

Energy consumption is one of the core issue in underwater sensor networks. Energy consumption is the total energy consumption to deliver a certain number of packets from sources to sink. This metric shows the energy efficiency of the MAC protocols. On the other hand, energy consumption is calculated by multiplying power consumption with required time.

$$Energy\_consumption = Power\_consumption.Required\_time \tag{3.50}$$

Here, the RequiredTime can be determined from equation (3.29) for BMF-M and from equation (3.31) for BMF-R.

3.11 Summary

In this chapter, to solve high end-to-end delivery latency of handshaking-based MAC protocols, a new low latency medium access control protocol while ensuring energy efficient operation, Bidirectional Multi-flow MAC protocol has been depicted to handle variable traffic load patterns of UW-ASNs. The operation cycle, the control frame structure, multi-hop multi-flow data transmission and packet transmission over reverse flow direction of proposed protocol are outlined in this chapter. Transition diagram and algorithm for data transmission technique for both sender and relay node have been evolved as well. Finally, the equation of energy consumption, end to end delay, throughput and frame error probability of proposed BMF-MAC protocol are derived to carry out performance evaluation.

Chapter 4

Results and Discussion

Aftereffects of the numerical model clarified in part three are exhibited in this section. At first, the system topology and fundamental trial setup for the proposed BMF-MAC convention is depicted. We utilized framework parameters of BMF-MAC convention like existing CMRT convention for examination which are displayed in Table 4.1, and 4.2. The exhibition of BMF-MAC convention regarding vitality, throughput and idleness is assessed utilizing reproduction apparatus MATLAB [44]. At long last, so as to research the productivity of the proposed BMF-MAC convention, an exhibition correlation between proposed BMF-MAC convention and existing CMRT conventions is completed.

4.1 Analytical Analysis

For our systematic investigation we consider a multi-jump topology of 36 static hubs which are put in a 5000 × 5000 m^2 square zone which is represented in Figure 4.1.

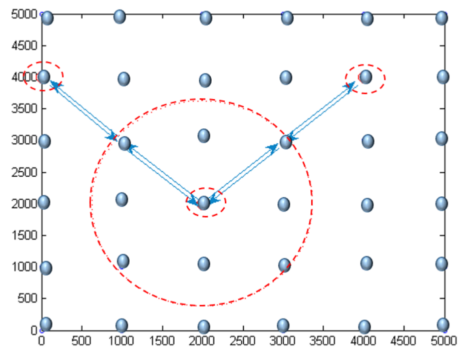

Figure 4.1: The network topology for analysis

The separation between two hubs are 1000 m in lattice dispersing. The transmission scope of hub is 1.5 occasions the matrix dividing, i.e., 1500 m. Here, we accept each hub has a similar transmission control. The majority of the hubs are expected to include precisely eight neighbors inside its range which is demonstrated by the spotted hover in Figure 4.1. The normal transmitting and accepting force is 2W and 20 mW of the acoustic handset. The acoustic channel is thought to be mistake inclined.

4.2 Experiment Setup

In our investigation structure, the system parameters and parcel parameters have been set for BMF-MAC are appeared Table 4.1 and Table 4.2 individually. The size of information parcel is fixed 1200 bits as in CMRT convention. The size of control parcel MFP is 128 bits, which is one byte longer than that of CMRT convention.

Table 4.1: Systems Parameters

Parameters	Value
Acoustic propagation speed	1500 m/s
Transmission rate	9600 bps
Buffer Capacity(N_{max})	300 packets
Minimum back-off counter	1
Maximum back-off counter (B_{max})	64
Bit Rate	1200 bps
Tx Power	2 W
Rx Power	20 mW
Idle Power	0.8 mW

Table 4.2: Packet Parameters

Parameters	Value
Data packet size	1200 bits
Control packet size	128 bits

4.3 Results and Discussions

In this subsection, we dissect the exhibition of the proposed BMF-MAC convention. BMF-M is a form of BMF convention, where just multi-stream information transmission is considered. Actually, BMF-R considers multi-stream bidirectional information transmission. Various outcomes are concentrated by three diverse execution measurements: inertness, vitality proficiency and throughput. Execution of both form BMF-MAC convention is contrasted and the current CMRT convention dependent on the condition determined in section three.

4.3.1 Throughput

In this subsection, the exhibition of throughput of BMF-MAC convention is assessed. We consider the exhibition of throughput as indicated by various offered loads, various separations, number of streams, distinctive system regions, number of turn around bundles and BERs.

4.3.1.1 Effects of offered loads

The throughput model which is clarified in area 3.9 is utilized. Figure 4.2 demonstrates that the information throughput of proposed BMF-MAC convention and existing CMRT convention in various offered loads with BER of 10^{-3}. The x-hub demonstrates the offered burden while the y-hub demonstrates the throughput as far as bit every second (bps). It is perceived that BMF-MAC displays the best execution as far as throughput in all offered burden conditions. In addition, the framework throughput shows the information parcels which is gotten by both transfer and last goal hubs effectively.

The framework throughput shows the general channel usage by utilizing the MAC convention correspondingly. Along these lines, it is indistinguishable from standard-

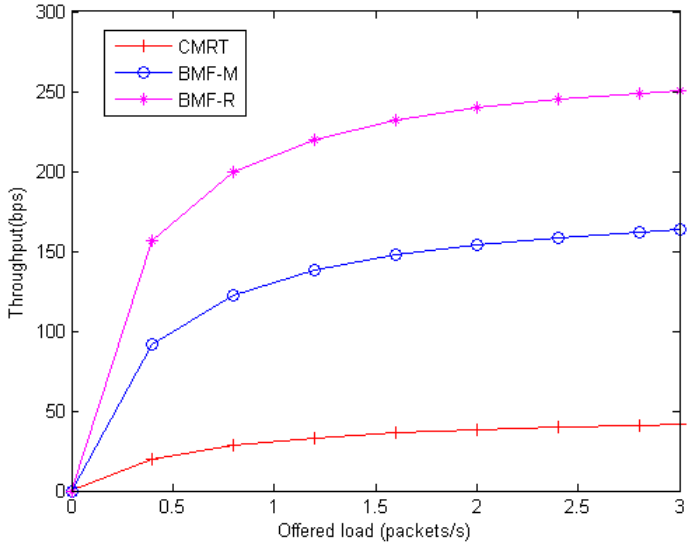

Figure 4.2: Performance comparisons of BMF-MAC with CMRT in terms of throughput

ized throughput per hub. Thus, it tends to be inferred that, as far as channel usage, BMF-MAC outperforms other option. In rundown, BMF-MAC convention outflanks CMRT convention with respect to information throughput in factor traffic loads.

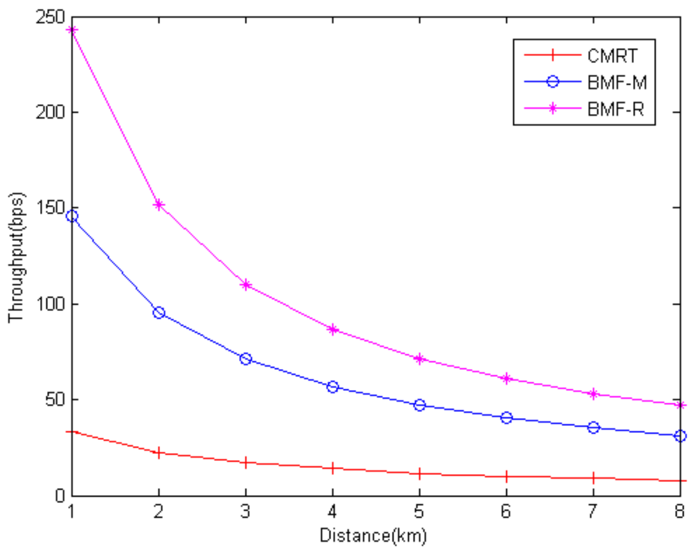

Figure 4.3: Performance comparisons of BMF-MAC with CMRT in terms of throughput

4.3.1.2 Effects of inter nodal distance

4.3.1.3 Effects of number of flows

The throughput of proposed BMF-MAC protocol and existing CMRT protocol with the increase of number of flows is illustrated in Figure 4.4. For BER 10^{-3} and offered load 3.2 packets/second, the x-axis shows the number of flows whereas the y-axis shows the throughput in terms of bit per second (bps).

4.3.1.4 Effects of number of reverse packets

4.3.1.5 Effects of number of nodes

For various number of hubs, Figure 4.6 demonstrates the throughput for 0.4 parcels/s offered load. The x-hub shows number of hubs while the y-pivot demonstrates the throughput as far as bps. With the expanding of the quantity of hubs, the quantity of source hubs increments. In this way, more multi-stream developments can happen which encourages BMF-MAC convention to convey more information bundles which results improvement of throughput. All the more explicitly, for number of hubs 5, BMF-M MAC convention can accomplish throughput around 5.6% higher contrasted with CMRT. Then again, BMF-R picks up throughput around 9.6%

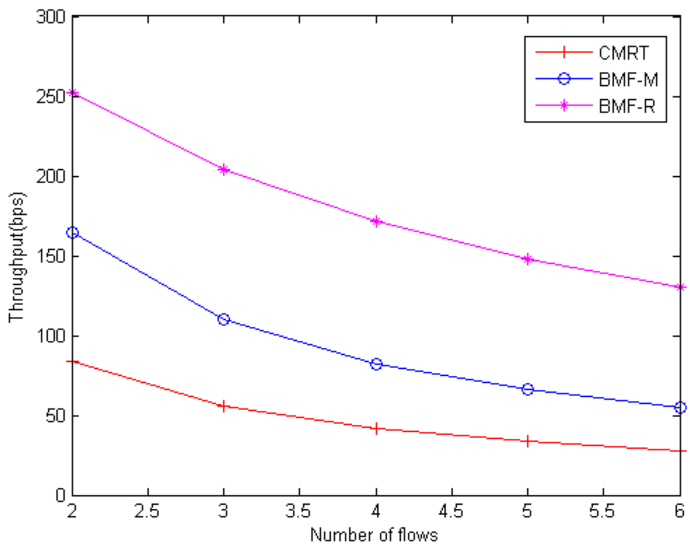

Figure 4.4: Performance comparisons of BMF-MAC with CMRT in terms of throughput

higher contrasted with CMRT convention. At the point when the quantity of hub is expanded to 40, BMF-M MAC can accomplish the most elevated improvement of throughput around 38.2% higher and BMF-R can increase 74.2% more than that of CMRT convention. That uncovers BMF-MAC convention is more throughput productive for enormous region organize. The previously mentioned data shows that, BMF-MAC beats CMRT concerning throughput with the expansion of system estimate. At last, we reason that the fourteen states in BMF-MAC altogether adds to the improvement of throughput with the expansion of number of hubs.

4.3.1.6 Effects of BER

For various number of BERs, Figure 4.7 translates the information throughput with offered load 0.8 parcels/s. Here, x-pivot demonstrates the BER while the y-hub demonstrates the throughput as far as bit every second. Various lines present the outcomes gathered with various conventions: BMF-MAC, RMAC LO-MAC. Throughput diminishes when the bit blunder rate increments from 0 to 1. It is seen that, the bidirectional multi stream information transmission strategy in BMF-MAC fundamentally adds to the improvement of throughput with the decline of BER.

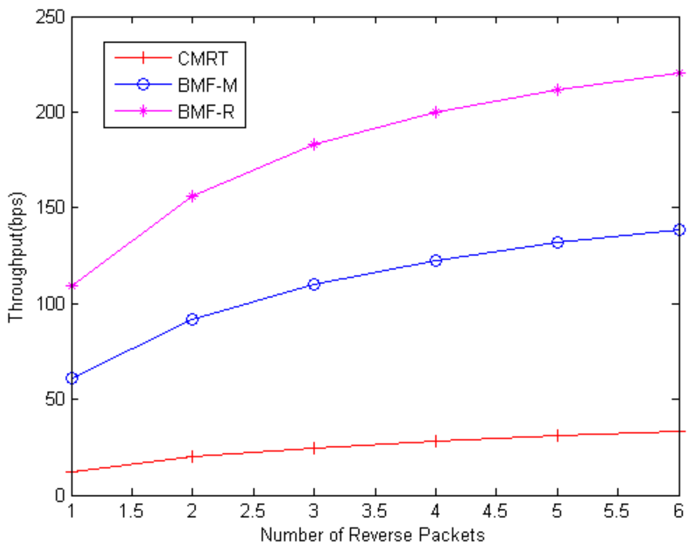

Figure 4.5: Performance comparisons of BMF-MAC with CMRT in terms of throughput

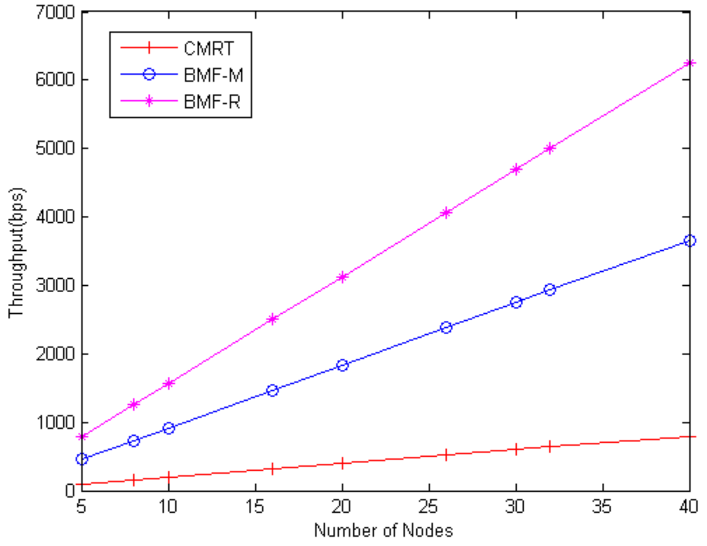

Figure 4.6: Performance comparisons of BMF-MAC with CMRT in terms of throughput

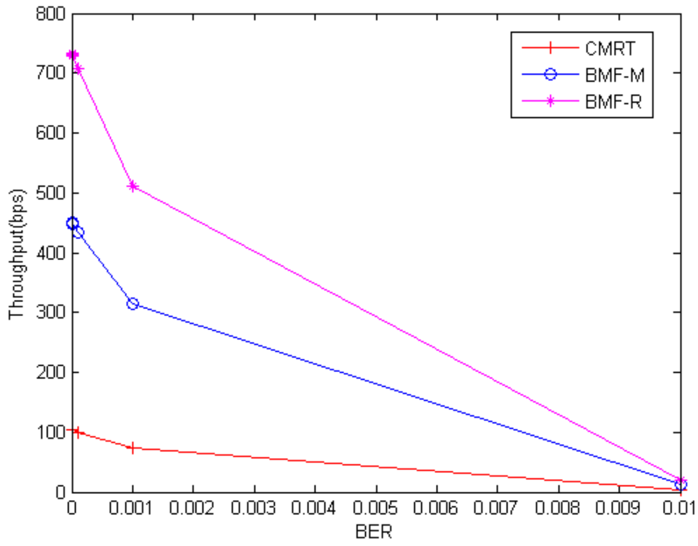

Figure 4.7: Performance comparisons of BMF-MAC with CMRT in terms of throughput

4.3.2 Latency

In this subsection, the presentation of start to finish conveyance inactivity of BMF-MAC convention is assessed. We ponder the exhibition of idleness as indicated by various number of jumps, various separations, number of streams, and distinctive piece blunder rates (BERs). The idleness model which is pondered in segment 3.6

is utilized.

4.3.2.1 Effects of number of hops

Start to finish bundle deferral of proposed BMF-MAC convention and existing CMRT convention in the variety of number of bounces with BER of 10^{-3} is displayed in Figure 4.8. The x-hub demonstrates the quantity of jumps while the y-hub demonstrates the inactivity as far as second (s). Various lines present the outcomes gathered with various conventions: BMF-M MAC, BMF-R MAC and CMRT. As can be seen from the figure, inertness increments when the quantity of bounces increments from 1 to 10. Likewise with the expanding of number of jumps, more bundles can be conveyed over various streams in a similar time prerequisite by BMF-MAC convention. Besides, during the time spent expanding of the jump number, BMF-MAC can transfer progressively bidirectional bundles backward stream heading. The convention allows progressively planned transmissions per round handshaking. Consequently, the convention is able to fundamentally lessen the time spent in information transmission and handshaking by methods for bidirectional information transmission over different streams.

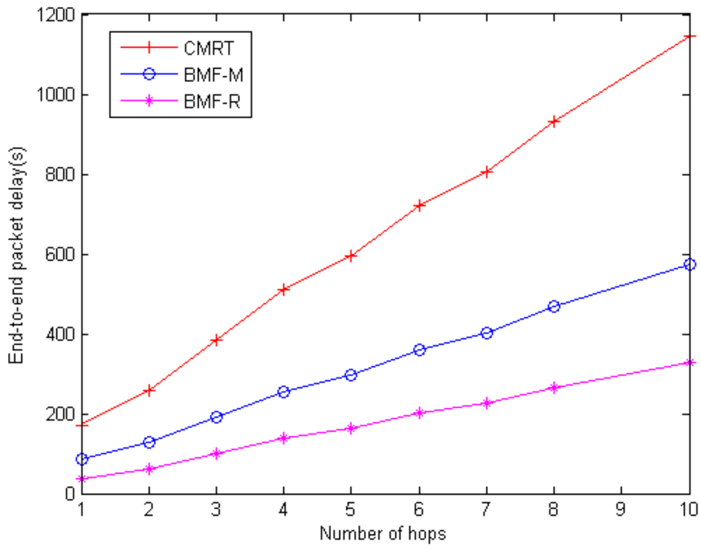

Figure 4.8: Performance comparisons of BMF-MAC with CMRT in terms of end to end packet delay

4.3.2.2 Effects of inter nodal distance

Throughput of proposed BMF-MAC convention and existing CMRT convention in the diverse number of switch parcels with BER of 10^{-3} is appeared in Figure 4.9. The x-pivot demonstrates the quantity of turn around parcels while the y-hub demonstrates the throughput regarding bit every second (bps).

Figure 4.9 uncovers start to finish postponement of proposed BMF-MAC convention and existing CMRT convention with the expanding of bury nodal separation of hub while BER is set to 10^{-3}. As the separation builds, the bustling span alongside the handshaking time raises by reason of delayed spread postponement. Along these lines, with the expanding of the all-encompassing holding up term the $Wait\_Flow$ state length broadens. This makes a hub need more opportunity to transmit bidirectional bundles in multi-stream situation. From Figure 4.9 it is appeared, while the separation is 1km, BMF-M MAC convention gives 10% less bundle postponement contrasted with CMRT convention. Moreover, while the separation is expanded to 4km, BMF-M MAC convention acquires inactivity around 25% lower than that of CMRT. On the off chance that the separation further is expanded to 8km, BMF-M MAC can accomplish the noteworthy decrease of idleness around 45% lower contrasted with CMRT convention. Straightway, BMF-R MAC convention in-

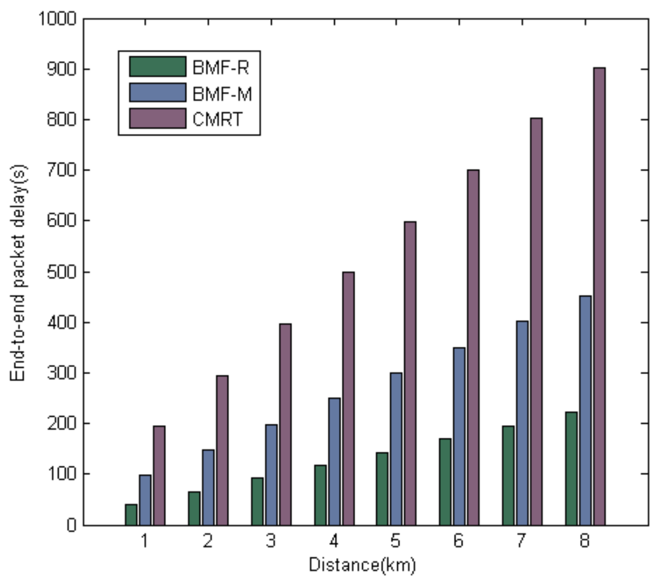

Figure 4.9: Performance comparisons of BMF-MAC with CMRT in terms of end to end packet delay

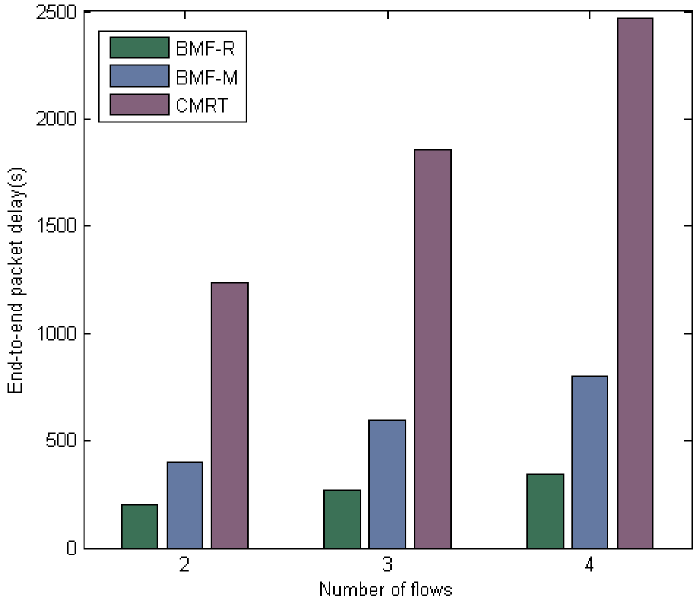

Figure 4.10: Performance comparisons of BMF-MAC with CMRT in terms of end to end packet delay

creases 15.2% less bundle postponement contrasted with CMRT convention for bury nodal remove 1km. For the separation 4km, BMF-R MAC convention gives idleness around 39.5% lower than that of CMRT. While the separation is expanded to 8km, BMF-M MAC can get the most astounding decrease of idleness around 69% lower contrasted with CMRT convention. Consequently, it is seen that, BMF-MAC can give better outcome to deal with variable traffic designs in multi-jump submerged sensor systems contrasting and CMRT.

4.3.2.3 Effects of number of flows

4.3.2.4 Effects of BER

For various number of BERs, Figure 4.11 deciphers the start to finish delay. Here, x-hub demonstrates the BER while the y-hub demonstrates the start to finish delay as far as bit every second. Various lines present the outcomes gathered with various conventions: BMF-MAC, CMRT. Throughput diminishes when the bit blunder rate increments from 0 to 1. The six new states in BMF-MAC fundamentally adds to the improvement of idleness with the expansion of BER. It is seen that, the bidirectional multi stream information transmission strategy in BMF-MAC essentially adds to the

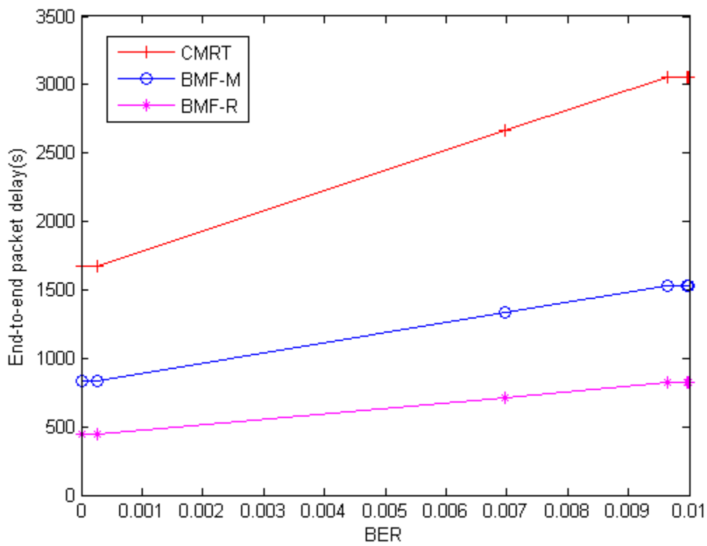

Figure 4.11: Performance comparisons of BMF-MAC with CMRT in terms of end-to-end delay

improvement of start to finish delay with the lessening of BER.

4.4 Energy Consumption

The performance of energy consumption of BMF-MAC protocol is evaluated in this subsection. We study the performance of energy consumption according to inter nodal distance, different number of flows, various offered loads and different number of nodes. The energy model which is presented in section 3.7 is used.

4.4.1 Effects of offered loads

The vitality utilizations of proposed BMF-MAC convention and existing CMRT convention with the expansion of offered burdens is outlined in Figure 4.12. The x-pivot demonstrates the offered burdens while the y-hub demonstrates the vitality utilization regarding joule (J). BMF-MAC lessens transmission time as it enables hubs to transmit at the same time when there is different information to transmit over multi stream. Subsequently, it needs less vitality than CMRT convention in all rush hour gridlock load situation. Since BMF-MAC needs less control bundles trade than CMRT conventions it additionally requires less vitality in all rush hour gridlock burden condition. In addition, information parcels can be conveyed over ordinary and turn around stream heading without conspiracies utilizing six distinct states in BMF-MAC convention. All the more explicitly, it is seen that in low rush hour gridlock load for offered load .2 bundle/s, the vitality utilization of BMF-M MAC convention can accomplish around 28% lower contrasted with CMRT convention. Then again, BMF-R expend vitality around 30% less contrasted with CMRT convention. For high traffic load, when the offered burden is 1.6 bundles/s, BMF-M MAC can accomplish the most astounding decline of vitality utilization around 74% less contrasted with CMRT. Besides, BMF-R increases 81% less vitality utilization contrasted with that of CMRT. Appropriately, BMF-MAC outperforms CMRT in regard to vitality utilization under factor traffic loads.

4.4.2 Effects of number of nodes

For various number of hubs Figure 4.13 demonstrates the vitality utilization for offered load. The x-hub shows number of hubs though the y-hub demonstrates the vitality utilization regarding joule. For number of hubs 20, BMF-M MAC convention can accomplish vitality utilization around 37.5% less contrasted with CMRT. Then again, BMF-R picks up vitality utilization around 49.2% less contrasted with

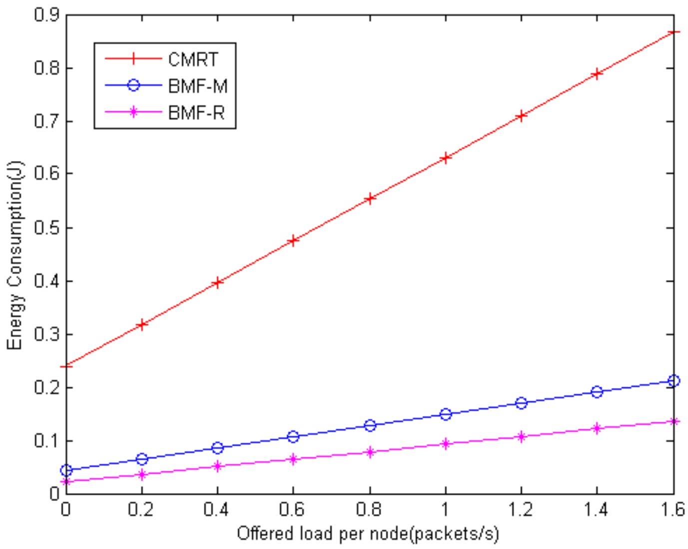

Figure 4.12: Performance comparisons of BMF-MAC with CMRT in terms of energy consumption

CMRT convention. At the point when the quantity of hub is expanded to 40, BMF-M MAC can accomplish the most noteworthy improvement of vitality utilization around 76% lower and BMF-R can increase 87.5% not as much as that of CMRT convention. That uncovers BMF-MAC convention is more vitality productive for huge zone organize. The previously mentioned data shows that, BMF-MAC beats CMRT as for vitality utilization with the expansion of system measure. As the quantity of source hubs increments With the expanding of the quantity of hubs. In this manner, increasingly bidirectional multi-stream developments can happen which encourages BMF-MAC convention to lessen control parcels overhead which results improvement of vitality utilization. At last, we reason that, the bidirectional multi-stream information transmission method in BMF-MAC essentially adds to the improvement of vitality utilization with the expansion of number of hubs.

4.4.3 Effects of number of flows

Vitality utilization of proposed BMF-MAC convention and existing CMRT convention in the variety of bury nodal separations with BER of 10^-3 is appeared in Figure 4.14. Here, offered burden is set to 0.8 bundles/s. The x-hub demonstrates the separations while the y-hub demonstrates the vitality utilization as far as Joule(J). It

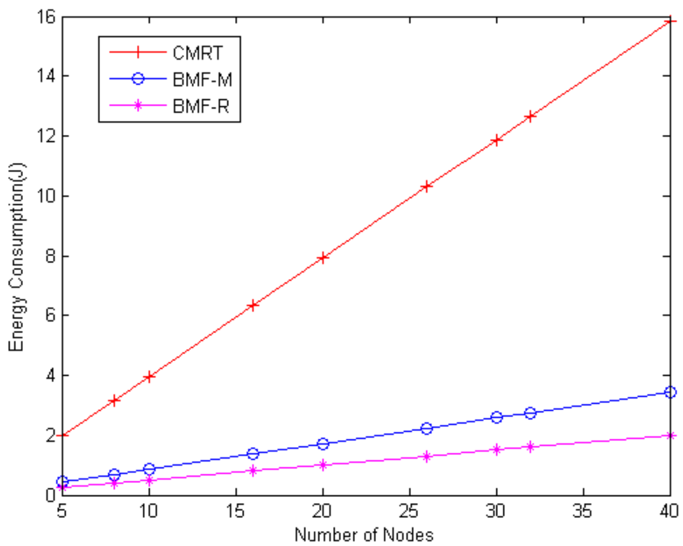

Figure 4.13: Performance comparisons of BMF-MAC with CMRT in terms of energy consumption

is shown that the exhibition of every one of the conventions as far as vitality utilization debases with the expanding of the between nodal remove, because of the ascending of the separation related correspondence overhead. As the separation improves, the bustling span alongside the handshaking time raises by reason of delayed engendering delay. Notwithstanding, it is seen that, BMF-MAC can give better outcome to deal with variable traffic designs in multi-bounce submerged sensor systems contrasting and CMRT.

4.4.4 Effects of inter nodal distance

Vitality utilization of proposed BMF-MAC convention and existing CMRT convention in the variety of entomb nodal separations with BER of $10^{-}3$ is appeared in Figure 4.14. Here, offered burden is set to 0.8 parcels/s. The x-hub demonstrates the separations while the y-pivot demonstrates the vitality utilization as far as Joule(J). It is displayed that the exhibition of every one of the conventions as far as vitality utilization increments with the expanding of the between nodal separate, because of the ascending of the separation related correspondence overhead. As the separation improves, the bustling span alongside the handshaking time raises by reason of delayed spread deferral. Nonetheless, it is seen that, BMF-MAC can give bet-

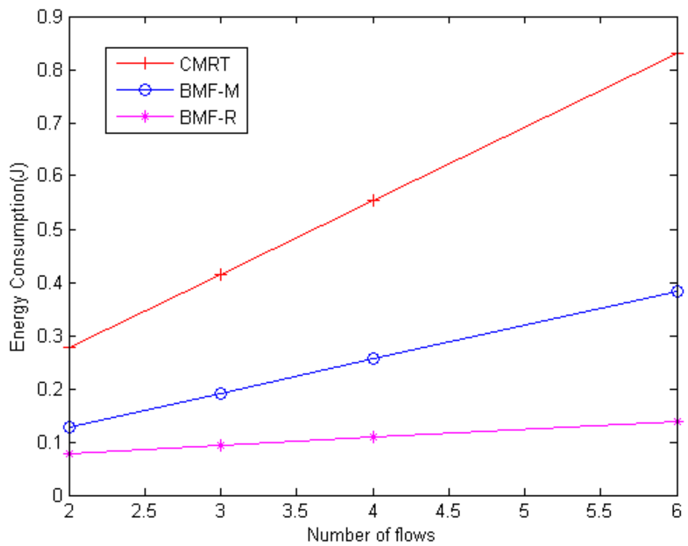

Figure 4.14: Performance comparisons of BMF-MAC with CMRT in terms of energy consumption

ter outcome to deal with variable traffic designs in multi-jump submerged sensor systems contrasting and CMRT.

In particular, From Figure 4.15 it is appeared, while the separation is 1km, BMF-M MAC convention gives 12.9% less vitality utilization contrasted with CMRT convention. Moreover, while the separation is expanded to 6km, BMF-M MAC convention gets huge decrease of vitality utilization around 74.7% lower than that of CMRT. Straightway, BMF-R MAC convention increases 14% less vitality utilization contrasted with CMRT convention in entomb nodal remove 1km. For the separation 6km, BMF-R MAC convention picks up the most astounding decrease of vitality utilization around 76.3% lower than that of CMRT. Consequently, it is seen that, BMF-MAC can give better outcome to deal with variable traffic designs in multi-bounce submerged sensor systems contrasting and CMRT.

4.5 Control Packet Time

Figure 4.15 demonstrates that the control parcel time of proposed BMF-MAC convention and existing CMRT convention in various offered loads with BER of 10^-3. The x-hub demonstrates the offered burden though the y-hub demonstrates the control bundle time regarding second. In BMF-MAC convention, numerous control

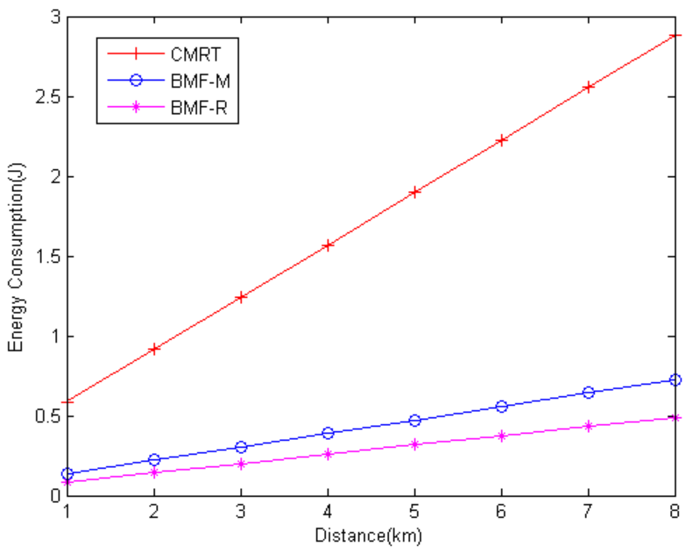

Figure 4.15: Performance comparisons of BMF-MAC with CMRT in terms of energy consumption

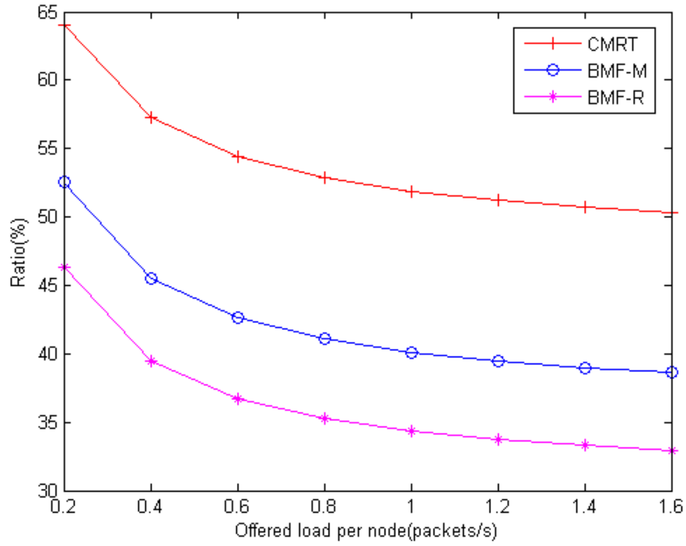

Figure 4.16: Performance comparisons of BMF-MAC with CMRT in terms of control packet time

edges can be traded at the same time; subsequently less control parcel time is required. Besides, while more bundles are created less control parcels are required by the BMF-MAC convention, therefore less control bundle time is required. It is perceived that, BMF-MAC shows the best execution as far as control parcel time in all offered burden conditions.

4.6 Throughput analysis of BMF-MAC over single flow

In this subsection, the presentation of throughput of BMF-MAC convention over single stream is assessed. BMF-S is an adaptation of BMF convention, where single stream information transmission is considered. Then again, BMF-SR thinks about single stream bidirectional information transmission. We examine the presentation of throughput as indicated by various offered loads, various separations and distinctive system territories.

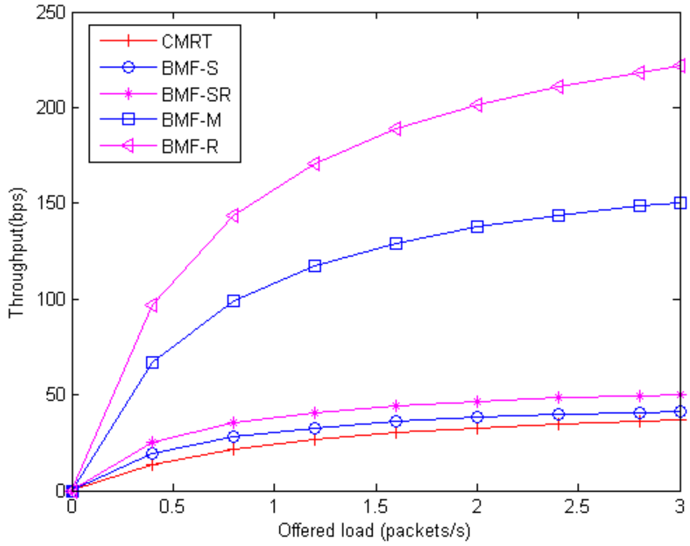

Figure 4.17: Performance comparisons of BMF-MAC with CMRT in terms of throughput

4.6.1 Effects of offered loads

Figure 4.17 demonstrates that the information throughput of proposed BMF-MAC convention and existing CMRT convention in various offered loads with BER of $10-^3$ for single stream. The x-hub demonstrates the offered burden though the y-hub demonstrates the throughput as far as bit every second (bps). Figure demonstrate that in all offered burden conditions BMF-MAC shows the best execution for single stream information transmission. Our channel reservation instrument enables a solitary sender to transmit information parcels to transfer hubs of single stream with retry bundle strategy and can decrease the absolute channel reservation overhead incredibly and in this way can improve channel usage. Accordingly, BMF-MAC has preferred information throughput over CMRT. Figure 4.17 uncovers that, in low rush hour gridlock load 0.5, BMF-S convention can accomplish throughput around 7% and BMF-SR accomplish 12% higher than that of CMRT. If there should arise an occurrence of high traffic load 3 bundles/s, BMF-S can accomplish information throughput around 3.5% higher contrasted with CMRT convention just as BMF-SR can accomplish the most noteworthy increment of information throughput around 13% higher contrasted with CMRT convention. In outline, BMF-MAC convention beats CMRT convention with respect to information throughput in factor traffic loads for single stream too.

4.6.2 Effects of inter nodal distance

In Figure 4.18, throughput of proposed BMF-MAC convention and existing CMRT convention in the variety of entomb nodal separations with BER of 10^{-3} is appeared. Here offered burden is set to 0.8 parcels/s. The x-pivot demonstrates the separations though the y-hub demonstrates the throughput regarding bit every second (bps). The exhibition of every one of the conventions as far as throughput debases with the expanding of the between nodal remove for single stream. All the more explicitly, Figure 4.18 uncovers that for littler entomb nodal separate 1km, the throughput of BMF-SR and BMF-S conventions can accomplish around 16.5% and 8% higher contrasted with CMRT convention individually. Then again, BMF-SR and BMF-S MAC convention can accomplish throughput around 6% and 3.5% more prominent than that of CMRT convention separately if there should be an occurrence of medium bury nodal remove 4km. Along these lines, BMF-MAC outperforms CMRT in regard to throughput with variable entomb nodal far off hubs.

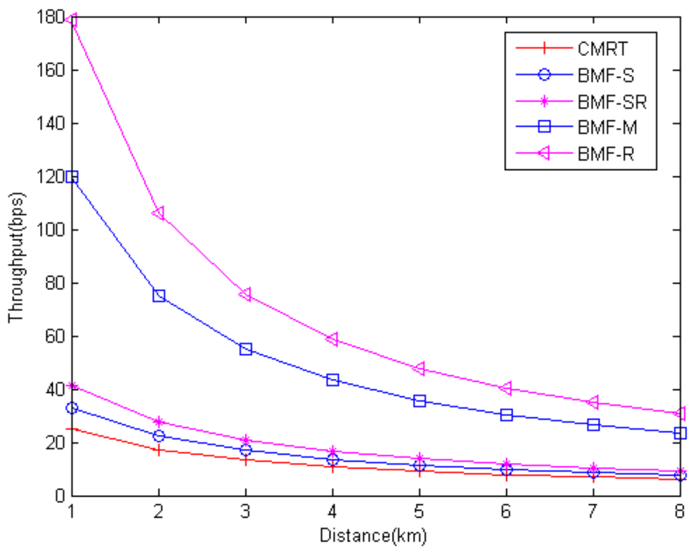

Figure 4.18: Performance comparisons of BMF-MAC with CMRT in terms of throughput

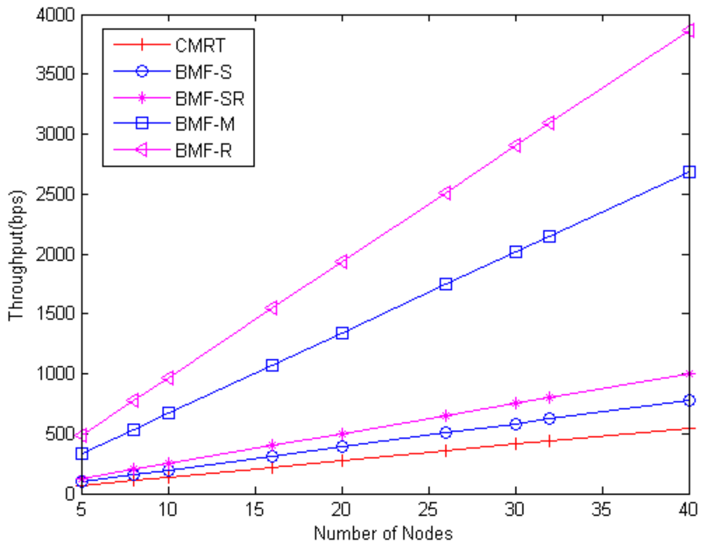

Figure 4.19: Performance comparisons of BMF-MAC with CMRT in terms of throughput

4.6.3 Effects of number of nodes

For various number of hubs, Figure 4.19 demonstrates the throughput for 0.4 bundles/s offered load. The x-hub shows number of hubs though the y-pivot demonstrates the throughput as far as bps. Truly, for number of hubs 20, BMF-S MAC convention can accomplish throughput around 16% higher contrasted with CMRT. Then again, BMF-SR picks up throughput around 31% higher contrasted with CMRT convention. At the point when the quantity of hub is expanded to 40, BMF-S MAC can accomplish the most elevated improvement of throughput around 24% higher and BMF-SR can increase 45% more than that of CMRT convention. The previously mentioned data demonstrates that, for enormous region organize BMF-MAC convention is more throughput productive. In this manner BMF-MAC beats CMRT as for throughput with the expansion of system measure for single stream information transmission also. It tends to be inferred that, the retry strategy of BMF-MAC essentially adds to the improvement of throughput with the expansion of number of hubs.

4.7 Summary

The performance evaluation results in terms of energy consumption, packet latency and throughput of proposed BMF-MAC protocol are investigated in this chapter. Furthermore, to show the suitability of proposed protocol, performance comparisons of proposed BMF-MAC protocol with that of existing CMRT protocol are carried out. Result shows that BMF-MAC protocol is superior to CMRT protocol in terms of end to end delay with the largest improvement of 88% in high number of flows. BMF-MAC saves more energy under variable traffic loads. In case of high traffic load, BMF-MAC can achieve the highest increasing of data throughput around 67.5% higher than CMRT. The analysis shows that the proposed MAC protocol performs better by decreasing the end to end latency and energy consumption while increasing the throughput in UW-ASNs under all traffic load case. Thus, the proposed BMF-MAC surpass existing CMRT protocols to handle variable traffic load patterns.

Chapter 5

Conclusion

5.1 Conclusion

Due to the long propagation delay in underwater environment of the acoustic signal, the designing of handshaking-based MAC protocol is more complex to avoid any collisions in under water environment. A large of works have been proposed to reduce the time-related overhead caused by the propagation delay.

This thesis aims at designing an energy efficient and low latency MAC protocol, Bidirectional Multi-Flow MAC (BMF-MAC) protocol, to handle multi-hop multi-flow data transmission under varying traffic load patters for UW-ASNs. In our protocol, data transmission with bidirectional multi-flow packet method is developed to allow sender to send multiple MFP frame to different receivers with parallel reservation of channels. Moreover, retry packets transmission technique is introduced for sending missing packets in each round handshake. Furthermore, pioneer transmission of a CTS frame is sufficient for transmission of data packets in reverse flow direction without exchanging of control packets thus reducing control packet overhead. Fourteen different states are founded for facilitating to transmit packets without any collision.

In order to evaluate the performance of the proposed BMF-MAC protocol, a mathematical model is derived which includes the equation of energy consumption, latency, throughput and frame error probability. Based on this model the performance of the proposed approach is examined in terms of performance parameters such as throughput, end-to-end delay, and energy consumption.

Furthermore, in order to show the efficiency of the proposed scheme, the performance of the proposed BMF-MAC protocol with the existing CMRT protocol has been compared. Results show that, BMF-MAC protocol can reduce end to end delay more efficiently. This is because, CMRT only transmits train of data per round handshake to multi-hop relaying nodes in a single flow. The BMF-MAC protocol permits more scheduled transmissions per round handshaking by exchanging of control packets and data packets in different flows simultaneously. Thus, in BMF-MAC protocol latency is decreased with the increase of different number of flows comparing existing CMRT protocol. The result shows that BMF-MAC protocol provides 40% less packet delay compared to CMRT protocol for data transmission over double flow, whereas for data transmission over high number of flows BMF-MAC can achieve the significant reduction of latency around 88% lower than that of CMRT protocol.

This is due to fact that, in BMF-MAC, channel reservation mechanism allows a single sender to transmit data packets to multiple nodes of different flows with per round of channel reservation and can reduce the total channel reservation overhead greatly and thus can improve channel utilization. BMF-MAC can achieve the highest increase of data throughput, around 67.5% higher than that of CMRT protocol in high traffic load patterns. The analysis shows that the proposed MAC protocol performs better by decreasing the end to end latency as well as energy consumption while increasing the throughput in UW-ASNs. Therefore, the proposed BMF-MAC protocol outperforms existing CMRT protocol.

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