Comparative Analysis of OFDM MIMO and IDMA OFDM MIMO using Aqua Sim Simulator for Underwater Communication

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Abstract. Underwater wireless acoustic communication is a central aiding skill used in underwater monitoring with the help of sensor nodes. Designing Underwater wireless networking is challenging as the water environment is dynamic as well as hard. In this paper we combine OFDM MIMO with IDMA to improve the network performance. The experimentation was simulated using Aqua Sim simulator an underwater imitation software that is based on NS2. The key objective of our paper is twofold. First is connection of communication functionalities such as BPSK modulation, Turbo code, Random Interleaver, UWMAC and three routing protocols. This implementation has modulation scheme, MAC and routing protocol from Aqua Sim simulator. Where the novel contribution to the work is implementation of Turbo code in NS2 for the appealing results. Secondly the OFDM MIMO and IDMA OFDM MIMO implementation is tested with 50 nodes and the various parameters such as BER, Throughput, delay, packet delivery ratio, energy consumption has been investigated. IDMA OFDM MIMO gives good results in terms of BER, packet delivery ratio, Throughput but consumes more energy.

Keywords: Acoustic networks, Aqua Sim, AODV, HH_VBF, Interleaver, Turbo Code, VBF.

1. Introduction
Underwater Acoustic Sensor Networks are used in underwater for collecting data from 3-dimensional zone of interest. The sea is an energetic and complex broadcast environment [1]. Since high proportion and high speed of fascination optical and electromagnetic communication can’t be used in Underwater Sensor Network. These influences to use of acoustic modems in communication among nodes. In underwater communication every node placed under the water gathers the data and forward the data to the online surface station through acoustic wireless communication [2]. Underwater wireless acoustic communication offers new challenges that is not detected in traditional wireless systems, as dynamic and slow speed of propagation and bandwidth is limited. In the acoustic wireless communication channel these results in hard probabilistic fault. The current standard to study the underwater communication performance is by one of the following methods: 1) software simulations, where in mathematically the physical channel is exhibited; 2) hardware in twist emulators, it includes the real acoustic modems instead of physical channel models; and 3) real time experiments, where in a network is installed in a real environment.
Underwater Wireless acoustic Sensor Networks (UWASN) involves of numeral of nodes and underwater autonomous automobiles that perform cooperative monitoring work in a sea atmosphere [4]. Underwater Wireless Sensor Network consists of number of requests as oceanographic information gathering, monitoring underwater pollution, offshore survey, strategic investigation and detection of disaster and quantity. Underwater Acoustic network with moving nodes creates mobile Underwater Wireless Instrument Network [5]. Underwater Wireless Sensor Network (UWSN) and Wireless Sensor Network (WSN) have some shared properties, namely node concentration is high and energy supply is limited. UWSN and WSN however vary in many features such as channel is acoustic, latency is high, movement of sensor nodes, probability of error is high, and 3D topology of network. However, these environments introduce many competitions in scheming UWSNs [6]. With water flow nodes moves in underwater sensor communication. As sensor nodes moves with flow of water Underwater Sensor Networks are movable. Underwater sensor nodes move with the speed of 2-3kilonots. This movement strategy results in an extremely dynamic system topology [7].

As the radio signals attenuate in Underwater, acoustic wireless channels are characteristically preferred. In air radio signal propagates at a speed of $3 \times 10^8$ meter/second, in water the acoustic signals propagate at a speed of approximately $1.5 \times 10^3$ meter/second [8]. Under water sensor network are constructed by the collaboration among number of sensor nodes, these nodes communicate bidirectionally through acoustic channels. UWSN contains number of nodes, they are installed in underwater atmosphere, number of base stations will be moving on the marine exterior with radio rate modems. In the underwater acoustic communication base station communicates through the wireless station using radio frequency. Communication in Underwater are extremely susceptible to errors since the acoustic channels used for communication is expressively affected by attenuation of the signal, different noise, effect of multipath, Doppler spread, turbulence and temperature of the water [9]. Because of these factors communication in underwater results in bit error proportion and interruption. Compare to terrestrial network underwater communication with sensor nodes have a complex node proportion and more packet damage possibility [10].

As the underwater acoustic channel has the special characteristic and the sensor nodes are mobile in the underwater, designing acoustic underwater wireless communication is thought-provoking. Aqua Sim simulator used for underwater is based on NS2 one of the widely used underwater simulator. Aqua Sim simulator effectively simulate underwater acoustic channels attenuation behaviour as well as collision performance in long delay acoustic networks. Channel of Underwater acoustic wireless communication is complex and simulation tools of physical layer used in Aqua Sim is often summarized. The paper is planned as, in segment 2 Underwater spread model is offered. In segment 3 system configuration is discussed briefly. Methodology is presented in segment 4. The Replication outcomes are made known in segment 5. Lastly, this paper is determined in segment 6.

2. Underwater acoustic propagation model

2.1. Attenuation

In an acoustic channel the attenuation loss that arises for an indicator of frequency $F$ ended distance $m$ is represented mathematically as

$$\alpha(m, F) = (m)^s \beta(F)^m$$

spreading factor is denoted by $s$, is absorption constant stated in $dB$, the path loss for acoustic channel is represented by

$$10 \log \alpha(m, F) = s \cdot 10 \log m + m \cdot 10 \log \beta(F)$$

In the above expression $s \cdot 10 \log m$ denotes the scattering loss, and $m \cdot 10 \log \beta(F)$ signifies the absorption damage. The geometry of spread is labelled by scattering loss $s$, for cylindrical scattering $s = 1$, for the actual real time scattering $s = 1.5$ (in a radio frequency the equivalent part for $s$ is pathway damage exponent and its price is typically in in the range of 1.999 and 3.999. For free space line of sight circulation $s$ is 2, and for the two ray ground reflection models $s$ is 4. Using the Thorp’s
method, the absorption constant can be stated as \( \beta(F) \) which is expressed in deciBel/kilometer for \( F \) in kiloHertz as [14]:

\[
10 \log \beta(F) = \frac{0.11F^2}{1+F^2} + \frac{44F^2}{4100F^2 + 2.25 \times 10^{-4}F^2 + 0.003}
\]

(3)

The above mathematical equation is effective for frequencies more than hundred Hertz.

\[
10 \log \beta(F) = 0.22 + \frac{0.11F^2}{1+F^2} + 0.011F^2
\]

(4)

The above mathematical equation is used for lower frequencies. As the frequency increases absorption coefficient increases. Absorption coefficient is the key cause which bounds the most practical occurrence for an acoustic connection of an assumed reserve. The pathway loss defines reduction of signal on an only sole, open broadcast route. If a quality of occurrence \( F \) and power \( P \) is communicated over this route, the acknowledged signal control assumed as \( \frac{P}{a(m,F)} \). If there are several propagation routes, individual of distance \( m_r, p = 0,1,2,3,4, \ldots \ldots P - 1 \), hence the network transmission function is written as

\[
T(m,F) = \sum_{r=1}^{P-1} \frac{\sigma_r}{\sqrt{a(m_r,F)e^{-j2\pi Fm_r}}}
\]

(5)

\( m = m_0 \) is the reserve among sender and receiver, \( \sigma_r \) is replicas of extra losses occurred in \( r^{th} \) pathway and delay is \( \eta_r = \frac{m_r}{c} \) (\( C = 1500 \) meter/second is the minimal speediness of acoustic waves in submerged). If the broadcast is not direction-finding, then propagation routes further the straight individual contributes to the recognized signal, then established power is \( |T(m,F)|^2 \).

2.2. Noise
In sea ambient noise is the combination of: turbulence, transport, breakers, and thermal noise. The ambient noise springs can be demonstrated as Gaussian data and a continuous power spectral density (p.s.d). The four noise mechanisms, p.s.d. as a role of occurrence in kHz can be written as:

\[
10 \log N_w(f) = 50 + 7.5w^{1/2} + 20\log f - 40 \log(f + 0.4)
\]

(6)

\[
10 \log N_t(f) = 17 - 30 \log f
\]

(7)

\[
10 \log N_s(f) = 40 + 20(s - 0.5) + 26 \log f - 60 \log(f + 0.03)
\]

(8)

\[
10 \log N_{th}(f) = -15 + 20 \log f
\]

(9)

For very low frequency region Turbulence effects can be seen \( (f<10Hz) \). In the frequency range \( 10Hz - 100Hz \) transport noise effect can be seen, and is exhibited using transport movement feature. Surface wave, produced by breeze obsessed waves is the main issue causing the noise in the frequency range \( 99Hz - 99kHz \) (is the range of acoustic arrangements). Thermal noise turns into main for \( f > 100kHz \).

The complete p.s.d of the ambient noise is given as

\[
N(f) = N_t(f) + N_s(f) + N_w(f) + N_{th}(f)
\]

(10)

The noise fallows through frequency, hence restricting the valuable acoustic bandwidth from below. In a frequency section the p.s.d. fallows linearly on the logarithmic scale. The succeeding rough calculation could be beneficial:

\[
10 \log N(f) = N_1 - \eta \log f
\]

(11)

2.3. SNR
The Signal to Noise Ratio (SNR) detected at a receiver end completed over \( l \) distance with attenuation \( A(l,f) \) and the p.s.d. of noise \( N(f) \) can be assessed as

\[
SNR(l,f) = \frac{P/A(l,f)}{N(f)\Delta f}
\]

(12)

Where \( \Delta f \) is the destination noise bandwidth.

3. Methodology
Designing Underwater wireless networking is challenging as the water environment is dynamic as well as hard. In this paper we combine OFDM MIMO with IDMA to improve the network performance. The
performance parameter is compared for IDMA OFDM MIMO and OFDM MIMO. Using Aqua Sim Simulator, the network performance was tested. The simulation set up is shown in Figure 1. Via simulation the performance is evaluated, conducted using underwater simulator Aqua Sim, written in NS2. Table I gives the different channel parameters. The presentation of proposed work is measured in terms of the Bit Error Rate (BER), energy, delay, Packet Delivery Ratio (PDR). We associate the presentation achieved by IDMA OFDM MIMO and OFDM MIMO in AquaSim simulator. In IDMA OFDM MIMO we use at physical layer Turbo code, Random Interleaver, BPSK modulation, Underwater MAC(UWMAC) at MAC layer and VBF, HH_VBF, AODV at network layer. In OFDM MIMO we use at physical layer BPSK modulation, Underwater MAC(UWMAC) at MAC layer and VBF, HH_VBF, AODV at network layer. The performance parameters PDR, delay, Energy, BER are measured. Instrument nodes are installed in our simulation. Installed sensor nodes are alike to every feature such as primary energy, initial power, range of transmission. In our work we use the frequency as 10kHz. The broadcast MAC protocol is used as in [10]. The experimentation was simulated using Aqua Sim simulator an underwater imitation software that is based on NS2. The performance parameters are shown Table 2.

![Figure 1. Scenario of Aqua Sim simulator](image)

| Channel                      | Underwater channel |
|------------------------------|--------------------|
| Attenuation prototypical     | Thorp’s model      |
| Size of packed send          | 50 bytes           |
| Ranging                      | 100m               |
| Data link layer              | Broadcast MAC      |
| Routing layer                | AODV, VBF, HH-VBF  |
| Number of nodes              | 49-50              |
| Reproduction period          | 500 seconds        |

4. Results and Discussion

IDMA OFDM MIMO and OFDM MIMO stand examined for several constraints such as Packet Delivery Ratio (PDR), Bit Error Rate (BER), delay, power consumption, throughput. In this work, our contribution is implementing Turbo code in AquaSim to improve the performance of IDMA OFDM...
MIMO. The results have been investigated and found encouraging for various performance parameters. The simulation result shows that the performance of the IDMA OFDM MIMO is appealing with Turbo code as well as increase in number of nodes.

For each routing protocol PDR is the important performance measures. The PDR is given by

\[
PDR = \frac{N(R_d)}{N(G_s)}
\]

(13)

\(N(R_d)\) is the amount of packets received effectively by the destination node, and \(N(G_s)\) is the number of individual packets generated from the current node. PDR is defined as the ratio of the packet received by the end point node to the packet send by the basis node.

For three underwater routing protocols VBF, HH_VBF, AODV with Turbo code we simulate the relationship of PDR vs the number of nodes.

| Nodes | PDR  | Consumed energy | Average end to end delay (ms) |
|-------|------|----------------|-------------------------------|
| 10    | 95.5709% | 11.53         | 1577.3                       |
|       | 99.85% | 7.69          | 48916                        |
|       | 95.56% | 13.55         | 1575.9                       |
|       | 94.95% | 24.77         | 1384.96                      |
|       | 50.58% | 13.42         | 1737.24                      |
|       | 50.589%| 11.027        | 1737.24                      |
| 25    | 96.95% | 16.84         | 2292.3                       |
|       | 96.91% | 41.41         | 2268.31                      |
|       | 96.94% | 19.81         | 2290.2                       |
|       | 96.97% | 38.74         | 2310.63                      |
|       | 52.695%| 15.70         | 2079.18                      |
|       | 52.695%| 12.903        | 2079.18                      |
| 50    | 98.2107%| 28.17         | 3904.6                       |
|       | 76.198%| 8.72          | 293.54                       |
|       | 98.266 | 34.36         | 4029.72                      |
|       | 85.61  | 11.68         | 485.772                      |
|       | 52.01% | 23.17         | 2951.62                      |
|       | 52.011%| 19.04         | 2951.62                      |

In our replication the amount of nodes is 50 and the simulation period is 500s. When the number of nodes is only 10 the IDMA OFDM MIMO and OFDM MIMO results PDR for VBF and HH_VBF is approximately same as in Figure 2 and Figure 3. As the quantity of nodes increases to 50, the PDR of IDMA OFDM MIMO increase as the Turbo code detects and correct the error. Where as in OFDM
MIMO PDR of VBF, HH_VBF reduces by 25%. IDMA OFDM MIMO and OFDM MIMO with AODV protocol performance remains the same as in Figure 4. From Table 2 it is seen that the performance of IDMA OFDM MIMO approach is improved for VBF, HH_VBF with Turbo code.

Figure 2. PDR with and without Turbo and VBF.

Figure 3. PDR with and without Turbo and HH_VBF.

Figure 4. PDR with and without Turbo and AODV.

Time taken by the source node to send the packet to destination node is expressed in terms of delay. Delay depends upon numerous features such as spread delay, calculation and waiting time. In the simulation numeral of nodes differs between 10 to 50. Duration of simulation is 500s. The delay of AODV protocol with IDMA OFDM MIMO and OFDM MIMO is approximately same shown in Figure 7. The delay of VBF, HH_VBF with IDMA OFDM MIMO is more as compared to OFDM MIMO shown in Figure 5 and Figure 6.
In the network performance assessment energy consumption is very important parameter. 

\[ E = E_t j + E_{rj} + E_{ij} \]  

(14) 

\( E_t j \) is the energy consumed to communicate packet by node \( N_j \). \( E_t j \) is the energy consumed to receive packet of nodes \( N_j \). \( E_{ij} \) is the energy consumed for idle overhead of node \( N_j \). The total number of sensor nodes are \( M \). In underwater acoustic communication energy consumption is due to energy consumed for collecting data, energy spent to send information packets, energy consumed to receive data, energy consumed for calculation and energy consumed during idle state.

The number of nodes in the simulation is 50. For each node the initial energy is \( J \). For transmitting state, the power consumption is 100W and for the idle state power consumption is 10mW. With time energy consumption of the node increases. The energy consumption with time for three routing underwater protocols is shown. Energy consumption increases with IDMA OFDM MIMO for routing protocols VBF, HH_VBF, AODV as the numeral of nodes upsurges as shown in Figure 8, Figure 9 and Figure 10. Whereas with OFDM MIMO energy consumed reduces compared to IDMA OFDM MIMO.
Bit Error Rate (BER) is defined as

$$BER = \frac{\text{total number of bits in error}}{\text{total number of observed}}$$

For the case of our work at physical layer OFDM MIMO, at MAC layer UWMAC, at network layer VBF, HH_VBF, AODV has been evaluated. The results are shown Figure 11, Figure 12 and Figure 13. For this combination BER is approximately $10^{-3}$. The BER is improved for the case of IDMA OFDM MIMO, at physical layer with Turbo code and Random Interleaver, at MAC layer UWMAC, at network layer VBF, HH_VBF, AODV has been evaluated. The results are shown. Bit Error Rate is approximately $10^{-5}$. 
5. Conclusion

The paper has been investigated for IDMA OFDM MIMO and OFDM MIMO with three routing protocols namely AODV, VBF, HH_VBF at network layer, UWMAC at MAC layer and Turbo channel coding technique at physical layer for various parameters such as Packet Delivery Ratio (PDR), Bit Error Rate (BER), delay, power consumption, throughput. In this work, our contribution is implementing Turbo code in AquaSim simulator to improve the performance. The results are compared for OFDM MIMO and IDMA OFDM MIMO. The results are simulated in AquaSim simulator. As the number of nodes increase for IDMA OFDM MIMO the PDR is improved by 25% compared to OFDM MIMO. BER for IDMA OFDM MIMO with cross layer is $10^{-5}$ and BER for OFDM MIMO with cross layer is $10^{-3}$. The performance is improved with Turbo code in terms of BER, PDR. Trade-off is, with IDMA OFDM MIMO the Delay and Energy Consumption increases compared to OFDM MIMO.
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