# Handover Protocol in Ad-hoc Diver Networks using Visual Light Communication


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***Abstract*** — During a deep sea diving, divers need a reliable network for dealing with emergencies and packet loss when communicating , so the ad-hoc infrastructure was proposed and could be implemented for a strong connection between diver's devices, however each diver in the underwater network is free to move independently in any direction, and will, therefore, change frequently its links towards other underwater nodes, reason why the handover mechanism is needed to ensure the quality of service, handle the ongoing data session while the diver's device is mobile or facing a signal degradation.



***Keywords — handover; QoS; Visual light, diver ad-hoc.***


## I. INTRODUCTION

Handover mechanism is the best solution for keeping and handling the communication while the device in the network is mobile. For the past decade, the detach and attach mechanism has been successfully implemented in telecommunication for dealing with the user equipment's mobility. This technique could be also applied on clustered-type underwater ad-hoc diver network, which is the goal of this paper.

An ad hoc network is a collection of wireless mobile nodes dynamically forming a temporary network without the use of any existing network infrastructure or centralized administration [1], this technology can be used in underwater to get strong communication between divers in order to reduce significantly the rescue delay and link disruption. However, clustered ad-hoc network will not stand alone without being supported by the handover mechanism for better, faster connection establishment and reliability.

Underwater network use different ways to transmit information. Wireless transmission of signals underwater over distances in excess of a 100m relies exclusively on acoustic waves. Radio waves do not propagate well in the underwater, except at low frequencies and over an extremely short distance (a few meters at 10 kHz) [1]. Optical signals, which are best used in the blue-green region (around 500 nm), also suffer from attenuation and do not propagate beyond about a hundred meters, although they do offer high bandwidths (on the order of MHz). Acoustic modems that are in use today typically operate in bandwidths on the order of a few kHz, at a comparably low center frequency (e.g. 5 kHz centered at 10 kHz). While such frequencies will cover distances on the order of a km, acoustic frequencies in the 100 kHz region can be used for shorter distances, while frequencies below a kHz are used for longer distances [2]. Visual light signal is a preferred communication technique because of its high bandwidth (430THz to 790 THz) and immunity to interference from electromagnetic sources [3]. In addition, the VLC is cheaper to implement and does not consume a lot of energy. In practice, these values can change depending on water temperature, depth, and other water's factors. Table.1. shows the characteristics of each medium.

| Medium | Bandwidth | Distance in practice | Energy consumption |
|---|---|---|---|
| Acoustic | < 10KHz | >100km | High |
| Radio waves | 10KHz | Very Short | High |
| Optical signals | < 1MHz | 500nm | High |
| VLC | 430 THz~ 790 THz | < 100m | Low |

Table 1: Comparative table of underwater media

For the purpose of this paper we are going to use visual light communication and its characteristics as the main signal while deploying the handover protocol.

## II. GENERAL ARCHITECTURE

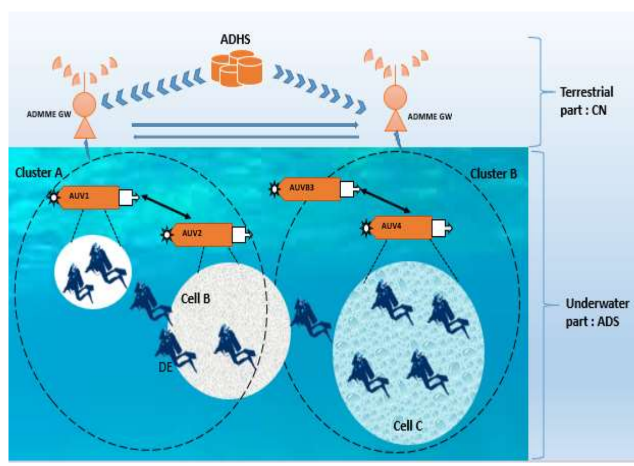


Figure 1 General Advanced Diver Network Architecture

### ✓ Architecture description

Fig.1. represents the proposed architecture for advanced diver network. The general architecture is composed of different elements described as following:

- ADHS: The Advanced Diver Home Server is a server found in the Core Network (CN), it contains all the information about all the divers and network parameters. When a new node appears from nowhere in the network the device will never be identified;
- ADMME GW: The Advanced Diver Mobility Management Entity Gateway is a sink node found in the Core Network; its main role is to manage the AUV's mobility;
- Cluster : A cluster contains AUVs and cells
- AUV: The Autonomous Underwater Vehicle is a node found in the Advanced Diver System; its role is to serve all the divers with a strong signal. The AUV is most of the time mobile. It contains different signals (Infrared, Visual Light, Acoustic, etc.) that can be used in a specific environment or for a specific need.
- DE: The Diver Equipment is a device used by divers for modulating and demodulating the transmitted and received signals. This device can be used to track a diver at a specific spot or to share data with the diver.
- Cell: The cell is an element located in the Advanced Diver system. It belongs to the AUV and each cell has its own Identity. Since each cell can use a specific signal, the sizes may differ depending on the bandwidth, frequency, spectrum for each channel.

| Element | Parameters | Role |
|---|---|---|
| **ADHS** | Diver's IDs, AUVs' IDs, cells ' IDs, Clusters 'IDs, type of media | Keep all the essential network 'information |
| **ADMME GW** | Diver's IDs, AUVs' IDs , tracking IDs | Manage the AUVs' mobility |
| **Cluster** | ID | Contain the AUVs and cells |
| **AUV** | ID, position, media used, number of divers allowed | Provide signal coverage and Manage the divers; deal with the inter AUV handover. |
| **DE** | DE's ID | Share data with other divers, allow the diver to be located |
| **Cell** | Cell's ID | Cover the zone depending on the signal strength |

Table 2 Requests and parameters

## III. AD-HOC DIVER NETWORK ARCHITECTURE

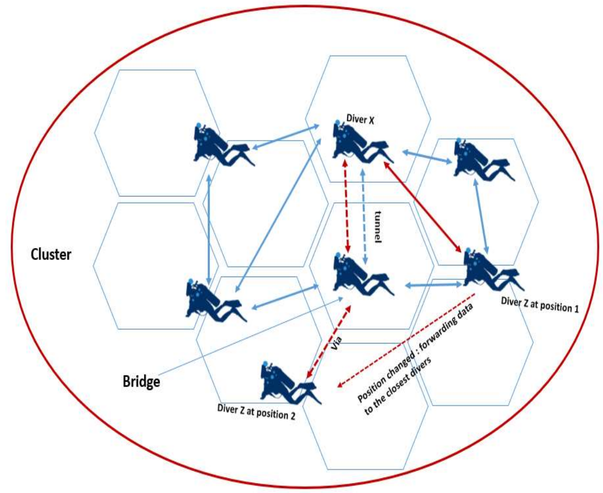


Figure 2 The suggested ad-hoc-based architecture

Fig.2. depicts the typical example of the inter diver's handover. In this figure, we have a diver Z at position 1 moving to another cell in the cluster called position 2. The diver Z at position 1 was close to diver X and could communicate easily without the need of any diver bridge. After moving to position number 2, the distance becomes longer, thus the diver Z must broadcast all the information with the help of diver X to all the surrounding divers before losing the signal, the divers cannot broadcast it, the handover will be unsuccessfully terminated.

The handover is triggered when the diver's signal starts reaching the minimal strength and must be accomplished when the diver connects successfully to another link; If not the handover is going to fail. So, our aim is to build the fastest ever handover protocol for advanced diver network, the protocol must fit the underwater environmental problems (the future is here). We are going to describe two scenarios, the first one will describe the scenario where the diver bridge is fixed and the second scenario is when the diver bridge is mobile (the most natural case).

## IV. HANDOVER PROCEDURE

### 1. Successful procedure with fixed bridge

The successful scenario is described in Fig.3. where the bridge is in static mode (immobile).

### ✓ Pre-condition

- The diver equipment (DE) must be known in the network and be connected;
- The DE must be in a connected state and must have ongoing data session because handover occurs only

when the device is in connected mode and not idle mode.

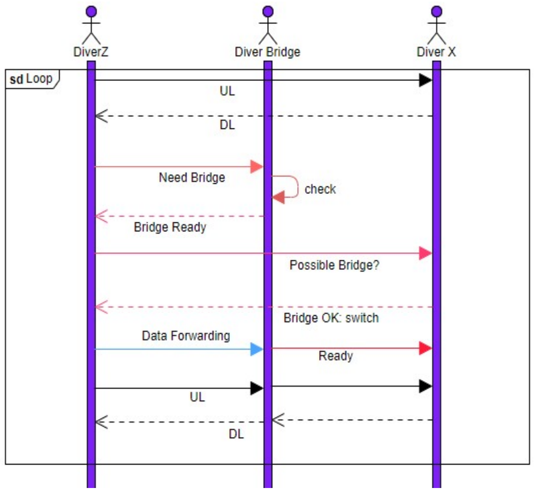


Figure 3 HO interaction with fixed bridge

✓ **Scenario**

a) The nodes X and Z (diver Z and X) are in connected mode and are sharing information (Ongoing session);

b) The node Z sends a measurement report to the node X, the measurement is triggered only when the signal reaches the threshold. This request contains useful information such as the frequency, the signal strengths from neighboring divers (each diver node has its own ID associated with its signal coverage distance) and the current signal strength;

c) When the diver Z signal strength reaches the fixed threshold (configured within each node), the measurement report is sent to the diver X, the node X (diver X) triggers an HO Request towards a target node (diver bridge). Handover request contains a useful parameter : The DE Id that needs a handover;

d) The Target node (diver bridge) gets a handover request from diver X and does the verification procedure that contains the current number of Des connected to that bridge, the maximum number of DEs allowed, if the node bridge can support the new node, it creates a bearer through which the data will be sent and received ( tunnel ID created)

e) After the verification step is done, the bridge node notifies the node X by sending handover acknowledgment request that contains tunnel ID and the bridge ID;

f) The node X gets a confirmation from the node bridge and performs 2 tasks: forward all data (current data status, the last sent and received packet) to the node bridge and send a handover confirmation and release message to the node Z that contains the tunnel and bridge node ID;

g) The node Z detaches from the old link and attaches to the new one by using received IDs.

✓ **Post condition**

The node Z is connected to the node bridge and performs again the same process of measurement report when the signal degrades or when it needs handover support.

### 2. Failure case with fixed bridge

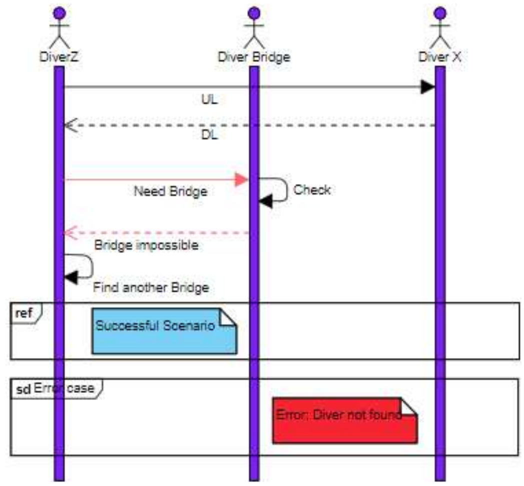


Figure 4 HO failure case with fixed bridge

Fig.4. shows the failure case where the diver bridge is not able to support other divers 'communication.

(1) The diver bridges check the availability

(2) If the diver bridge is saturated or cannot support a specific kind of channel, the "bridge impossible" message will be sent to the diver;

(3) The divers must look for another bridge if the other divers cannot play the role of the bridge; the handover is going to fail (diver bridges not available;

(4) If the request for the bridge is done successfully, the scenario in figure 3 will be initiated.

### 3. Successful case with moving bridge

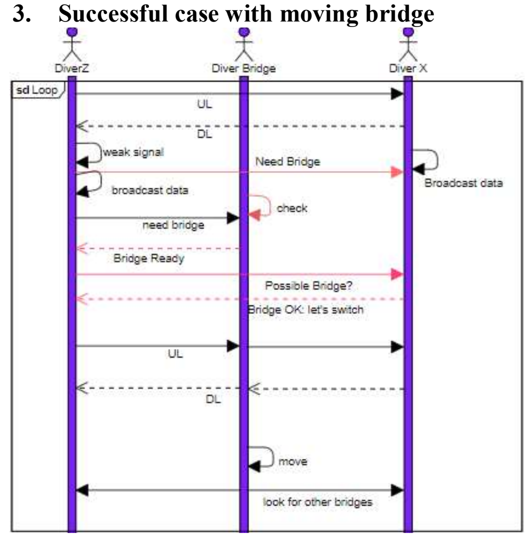


Figure 5 successful HO with mobile bridge

To avoid missing the diver bridge while switching, the handover must be done as soon as possible; even if the diver bridge moves after handover completion, the other divers can be used as bridges because they all have the broadcast messages (fig.5.). When the diver bridge starts moving, they notify the active divers in order to prepare another diver for bridging them (back to the same procedure).

(1) The weak signal message is triggered within the diver
(2) The process of broadcasting starts: all the surrounding divers with high signals will receive the data;
(3) When one of the bridges is available, they divers switch the path;
(4) If the bridge starts moving, it notifies the divers to look for another bridge; the divers broadcast the communication status again and switch to another available bridge. The failure scenario is shown below.

## 4. Failure case with moving bridge

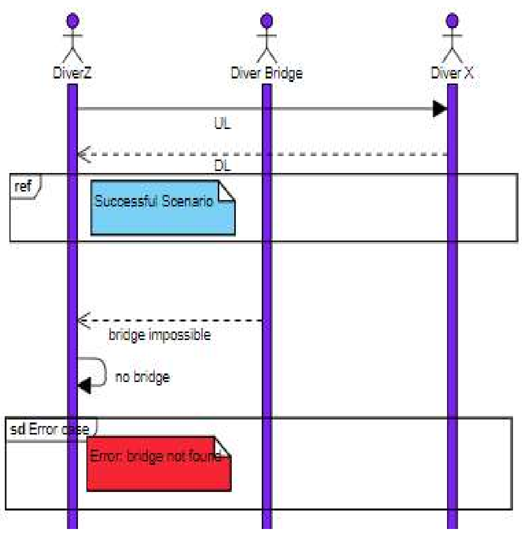


Figure 6 failure HO case with mobile bridge

Fig.6. represents the failure case where the diver bridge is saturated or cannot handle the handover.

(1) The diver Z sends the message to the diver bride to solicitate the handover;
(2) The bridge sends back the message to let know the diver Z about the situation (cannot handle the handover;
(3) For the critical case, the handover will be terminated
(4) The error message sent.

## 5. Connection states

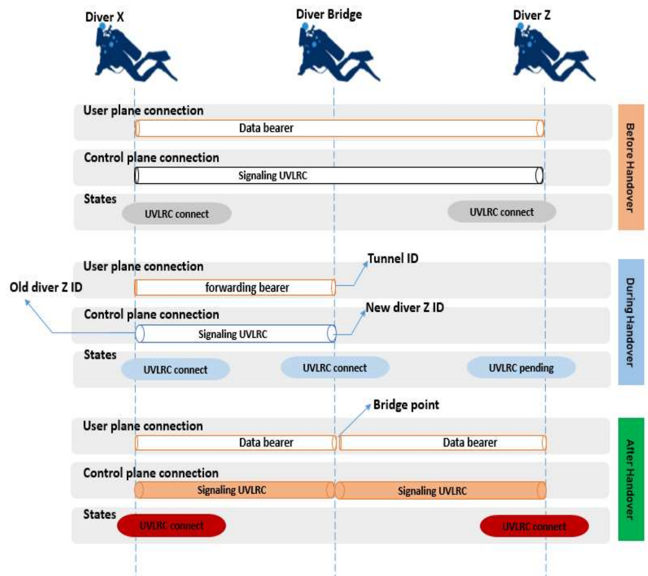


Figure 7 HO states and connection information

Fig.7. illustrates the connection establishments in the user and control planes, in addition, the diver's states before, during and after the inter diver's handover is shown.

➢ **Before the inter AUV handover**

Before the handover takes place, both divers 'UVLRC (Underwater Visual Light Resource Control) are in connected states. In the user plane, the data bearer is established and in the control plane, the signaling tunnel is set up for coordinating all the handover process.

➢ **During the inter divers handover**

During the handover procedure, the diver state is in pending mode for a while and the period has to be unnoticeable. Both divers stop sending and receiving until the handover takes place. The user data will be broadcast to all the divers and the signaling bearer will be established again for the next handover procedure. The divers will erase their old tunnel IDs from the old divers and get the new tunnel IDs. Since many divers can request for the handover at the same time, to identify each request and each tunnel through where each specific data pass, the tunnel ID is needed.

➢ **After the inter AUV handover**

After the handover is done, the data bearer is switched to the new bridge, the divers start sending and receiving the data via the new bridge. The states remain connected for the next handover. The bridge plays the role of a signal amplifier so that the divers can use the bridge's strong signal to communicate. Table.3. describes the parameters for each request:

| Function | Parameter |
|---|---|
| **Report; handover needed** | Channel used; frequency; signal strength from neighboring cells; current cell ID; current signal strength |
| **HO request** | Diver ID; channel used |
| **Check** | Current number of Divers, the maximum numbers allowed, bearer creation ID |
| **HO Ack** | AUV ID; the bearer ID, channel used |
| **Data transfer** | Data ID; packet first and last index; flag, diver ID (contains the first and last received packet) |
| **HO confirmation and Release** | Bearer ID; Diver ID |
| **HO not possible** | Reason; |
| **Check available AUVs** | All AUV lists, AUV IDs, |
| **HO aborted** | Reason; |
| **Broadcast** | Diver ID; signal used; position |
| **Connect to any AUV** | List of AUVs available; AUVs' ID; |
| **Release Link** | New Diver ID; AUVs 'IDs; |
| **Broadcast bearer** | Diver ID; packet first and last index; flag (contains the first and last received packet) |

Table 3 Requests and parameters

## V. THE PROPOSED PROTOCOL STACK

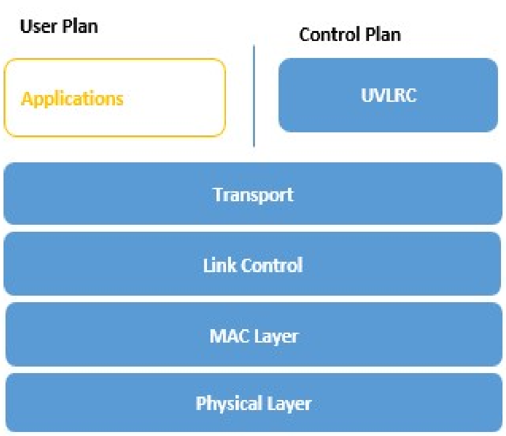


Figure 8 General Protocol Architecture

Fig.8. represents the proposed lightweight protocol stack suitable for HO mechanism in an underwater diver network.

- **MAC and Physical:** The MAC layer lies between the link control layer and the physical layer. It is connected to the link control layer through logical channels, and to the physical layer through transport channels. Therefore, the MAC protocol supports multiplexing and de-multiplexing between logical channels and transport channels. Higher layers use different logical channels for different QoS metrics. The MAC protocol supports QoS by scheduling and prioritizing data from logical channels.
- **Link Control**: In the transmitting side, the LC protocol constructs Link Control Packet Data Unit and provides the Link Control PDU to the MAC layer. The LC protocol performs segmentation and concatenation of transport PDUs during the construction of the LC PDU. In the receiving side, the LC protocol performs reassembly of the LC PDU to reconstruct the transport PDU.
- **Transport layer:** The transport layer supports the efficient transport of IP packets over the visual light link. It performs header compression, Access Stratum (AS) security (ciphering and integrity protection that we are not going to touch in this paper) and packet reordering and retransmission during handover.

After the transport layer the protocol is divided into two parts, the user plane and the control plane, the user plane contains the application layer and the control plane has the underwater visual light resource control protocol (where the handover is handled).

- **UVLRC layer:** The underwater visual light resource control protocol supports the transfer of the signaling. It also performs functions required for efficient management of the visual light resources and the whole handover mechanism between nodes.
- **Application layer:** This layer handles all things related to underwater diver's applications and data.

## VI. FURTHER STUDIES

There has always been a work in progress; the path has never been perfect, the reason why the proposed underwater handover protocol is still in his infant stage. It, therefore, must be improved by adding the security aspect, power consumption and much more things related to the water environment's challenges. Although we designed our own handover protocol, we still need further studies to enhance this mechanism. In addition, the protocol must be implemented, experimented and proved in real word by using the Zynq7000 board and a water tank.

In addition, we assume that the current underwater modem (diver equipment) can receive and transmit the data using a visual light signal, the ad-hoc architecture works perfectly as well. However, further research is still required to provide such a robust device and topology. The OFDM/MIMO techniques using visual light signal must be studied and implemented for load balancing during different handovers. As the project evolves, we may still face several steps that require more studies to reach our aim. Therefore, this paper does not depict an exhaustive list of all the possible underwater challenges to overcome.

## VII. SUMMARY

In this paper, we discussed how to deploy a hard handover protocol in clustered ad-hoc diver network in order to enhance communication flexibility and reliability. By adopting the handover concepts found in a telecommunication system (LTE), we presumed that the diver network is composed of cells, which form a cluster. Therefore, this lightweight version can handle easily the handover mechanism; provide seamless communication and quality of service while the diver is moving in any direction.

In addition, we showed the states before, during and after the handover procedure by using the sequence diagrams. The proposed protocol stack was explained, and further studies are needed for better experiment. The protocol requires more time to reach successfully its potential performance; therefore, the algorithms and implementation result will be shown in the next publication.

## ACKNOWLEDGMENT

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