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Underwater Routing Protocols for Funneling Effect and Energy Holes Avoidance

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Abstract: Underwater sensor network are susceptible to funneling effect and energy drain of sensors near the surface. However, to overcome these bottleneck links and estimate the nodes current energy and traffic a drain rate formula had been deployed exponential weighted moving average method to calculate the current energy of the nodes in the intensity region. Thus an exact energy estimate of the forwarding node can be calculated depending on its current status. Aqua Funneling and Energy Holes Avoidance with Directional Antenna (AFEHADA) uses single channel and it checks the packet drop rate channel utilization and decides whether to transmit or back off. Aqua Funneling and Energy Holes Avoidance with Optimal transmissions using Directional Antenna (AFEHAODA) with channel diverse capability and multi-interface support of which dedicated channel is used for transmission. This protocol checks the packet drop rate, time for channel utilization, residual energy and then decides whether to transmit or reroute. Comparisons of both the protocol were done with VAPR using ns2 simulator using aquasim patch.

Key words: Directional antenna, energy drain rate, channel diverse capability, AFEHADA, modes

INTRODUCTION

Sensor network architecture states that it has the responsibility of data collection and data routing (Akyildiz *et al*., 2002). However, due to the convergecast routing (Zhang and Huang, 2005) where all sensor nodes route towards a sink at a very short duration (Zhang and Huang, 2005) there exhibits funneling effect and energy holes problem. Routing holes are formed when nodes are not available or when there is a failure in the case of energy drain (Ahmed *et al*., 2005). Here in this paper discussion is based on the energy drain of sensors with one hop and two hop neighbours had been done on two protocols: Aqua Funneling and Energy Holes Avoidance with Directional Antenna (AFEHADA) and Aqua Funneling and Energy Holes Avoidance with Optimal transmissions using Directional Antenna (AFEHAODA).

Multipath routing can be coarsely classified as node disjoint (where primary path and backup path are mutually exclusive) as well as braided multipath (where there are several number of paths) (Ganesan *et al*., 2001). The research of effective hydrocast where forwarding was done with energy consumption throughput, packet delivery ratio and minimal propagation delay with triangulation with minimal detour paths (Anand and Titus, 2014) focuses upon patterned failure (connectivity loss) due to its geographical coordinates (Ganesan *et al*., 2001).

The problem with the underwater sensor network is that the nodes that are closer to the sink may drop many packets and may consume more energy than the other nodes which are in peripheral area. This is termed as the funneling effect (Wan *et al*., 2005). This region where funneling effect takes place is called intensity range which can be defined as the number of hops is smaller and the traffic intensity is larger is termed as intensity region (Ahn *et al*., 2006). The sequel of this study focuses on estimating the communication range with the aid of directional antenna at wireless sensor nodes which undergo funneling effect. The amelioration of the routing protocol proposed is focused only on frensel region and its path whereas the sink located on the surface is battery powered and does not run out of energy.

The protocols were simulated with ns2 simulator using aquasim patch along with VAPR (void aware pressure routing) (Noh *et al*., 2013) a fully stateful routing protocol with a beacon packet containing depth, direction, sequence number and hop count for forwarding. The primary attenuations were calculated with Ainslie and McColm (1998) for attenuation analysis incorporated in ns2 simulator. The temperature calculations measured

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with UNESCO models priory is used in analysing the in-situ to potential temperature that provides a more realistic environment configuration theoretically. Thus, a consolidated frame work has been provided for underwater sensor networks with simulation and analytical analysis for sea characteristics. The performance metrics shows that throughput goodput and energy consumption were better than the conventional VAPR. The closest to this attenuation model (Ainslie and McColm, 1998) the protocol proficient hydrocast with energy consumption had been proposed for void avoidance. However, it also deals with connectivity loss rather than focusing on the intensity region.

The remainder of paper is organized as discusses the analysis of underwater environment, literature survey of routing protocols, algorithm development of Aqua Funneling and Energy Holes Avoidance with Directional Antenna (AFEHADA) and Aqua Funnelling and Energy Hole Avoidance with Optimal transmissions using Directional Antenna (AFEHAODA) chapter results and discussion and chapter 6 conclusion and future work.

Underwater characteristics: The much of this work focuses on attenuation characteristic with Ainslie and McColm Model (Ainslie and McColm, 1998) and UNESCO model for temperature calculations. When dealing with physical acoustic at sea attenuations should be considered. The factors that affect attenuations can be quantified as frequency, temperature, acidity, depth and salinity. Due to the anisotropic effect of underwater environment for potential temperature calculations had been made with UNESCO Models with presumed *in situ* temperature.

The potential temperature value $\Delta\theta_1$ is calculated from the in-situ temperature (degree centigrade) t_0, salinity (parts per trillion) S_0 and pressure (kilopascals) p_0 as shown in Eq. 1 and the values are shown in Table 1. The value of ã states the absence of heat transfer between the system and the surrounding.

$$\Delta\theta_1 = \Delta p \gamma(S_0, t_0, p_0) \quad (1)$$

Where:

Δp = The reference pressure

γ = Adibatic value

$$y = \frac{\partial t^1}{\partial p^1}$$

Here, the assumption is made in Table 1 that the values of temperature changes associated with a depth of every one kilometre remains the same.

Table 1: Potential temperature calculations from in-situ temperature for depth till 10 km. The salinity value is taken as 35 ppt for calculations

Temperature (*in situ*) (°C)	Depth (m)	Potential temperature (°C)
7	1000	6.901
6	2000	5.803
5	3000	4.706
4	4000	3.610
3	5000	2.513
3	6000	2.377
3	7000	2.231
2	8000	1.122
2	9000	0.961
2	10000	0.791

Table 2: An example of attenuation analysis using ainslie and McColm for varying bandwidth

Potential temperature (°C)	Depth (m)	Frequency (kHz)	Ainslie and McColm (decibels per kilometers)
6.901	1000	10	0.933
5.803	2000	10	0.833
4.706	3000	10	0.744
3.610	4000	10	0.665
2.513	5000	10	0.595
2.377	6000	10	0.522
2.231	7000	10	0.460
1.122	8000	10	0.414
0.961	9000	10	0.367
0.791	10000	10	0.327

Ambient noise: The propagation of high frequency waves near the surface were funneling effect takes place is affected by bubble clouds, distribution of bubble size and breaking waves (Farmer *et al*., 2001). So to quantify the noise with frequency and temporal changes, this research is shown using Eq. 2:

$$10 \log_{10} N(f) = 50- 18 \log (f) \quad (2)$$

Where:

N = The noise frequency and the value of f is is frequencyin the units of Hz

(f) = This approximation is valid for the frequency range of tens of Hz up to tens of kHz (Stojanovic, 2007)

Ainslie and McColm: The model provides a wider range of utilization with varying depth and acidity which is calculated by Eq. 3 and the values are shown in Table 2:

$$10\log\alpha(I,d,t,f) = 0.106\frac{f_1 f^2}{f_1^2 f^2}\frac{pH8}{e0,56} + 0.52 \left(1+\frac{T}{43}\right)\left(\frac{S}{35}\right)\frac{f_2 f^2}{f_2^2+f^2}e\frac{-D}{6} + 4.9\times10^{-4} \quad (3)$$

Where:

T = Temperature

D = Depth

S = Salinity

The pH (acidity) is the log10 of the hydrogen ion concentration. The f denotes frequency of signal. The relaxation frequencies of f_1 and f_2 are found using Eq. 3 and 4:

$$f^1 = 0.78\sqrt{\frac{S}{35}}\, e^{\frac{T}{26}} \quad (4)$$

$$f_2 = 42e^{T/17} \quad (5)$$

Literature review: Directional antenna reduces the energy holes problem by increase the communication range of nodes nearby the sink. Similar analysis of Directional Antenna at Sink (DAaS) (Cho *et al*., 2006) which increases the network lifetime with sensor networks has been found in where a sink beam pattern using sleep and wake up scheduled algorithm (Cho *et al*., 2006). How to attain connectivity in a directional antenna had been proposed with poisson and geometric distribution (Daltrophe *et al*., 2015). Since, the simulation in this paper uses terrain wherein nodes are configured with dense topology, definitely there will be a node that provides the opportunistic contact-based routing.

A Fair Data Transmission Strategy (FDTS) (Yuan *et al*., 2014) was proposed to avoid collisions in the MAC layer and to attain equality in throughput. It uses queue management, transmission control and competition waiting. Queue management was based upon the time distance ratio with respect to the propagation time of a packet at that instant and the time required for travelling to reach the sink divide by the entire distance. Transmission control checks that a fair amount of throughput is available to all of the sensor nodes irrespective of their distance by assigning a weight value based on the time distance ratio and competition waiting eliminates congestion and prolongs the network lifetime (Yuan *et al*., 2014). This approach tries to attain fairness in data transmission with all the nodes rather than trying to alleviate the funneling effect. Thus the literature stated above uses either the sink for avoiding funneling effect as in Cho *et al*. (2006).The other approach with autonomous underwater vehicle like data mules approach as in U-Fetch (Favaro *et al*., 2013) with a combination of multi-hop signaling and polling (Favaro *et al*., 2013) incurs extra energy cost.

Directional antenna radiates power in one direction with maximal directivity whereas omnidirectional antenna radiates power non-directionally that is in all direction (Balanis, 2016). The conventional network simulator (ns-2) support uses omnidirectional antenna, whereas directional antenna usage in opportunistic routing increases the transmission distance and has less lobe and higher gain (Yina *et al*., 2012).

The features of directional antenna in multi-channel MAC used in wireless local area network discuss when a multi-hop RTS frame is received. Antenna beamform changes along the direction of sender wherein CTS data and ACK are received in single hop frames (Ko *et al*., 2008). From the literature it is evident directional antenna plays a vital role in eliminating funneling effect with reduced power consumption.

MATERIALS AND METHODS

Algorithm development: The flow chart describes the scenario where nodes route greedily upwards towards the sink using the normalized advance with cost as throughput with the suitable forwarder in the water column (terrain) with attenuation calculation using Ainslie and McColm (Fig. 1).

It is assumed that underwater sensor nodes have passive node mobility and their no change in network density due to node mobility. Finally data is taken by eulerian approach wherein data are taken at that point at that instant of time. Since, the usage of passive sensor that float on preset depth and the changes associated with vertical movement is less affected.

If the nodes are within the intensity region then the energy drain rate is calculated with exponential weighted moving average and depending on the criteria it decides whether to forward or not. The new value of energy drain rate is calculated after every 5 sec.

Aqua Funneling and Energy Holes Avoidance with Directional Antenna (AFEHADA): All nodes initialize the surface id and depth. Then, the sonobuoy initializes the position of all nodes with its control packet after every 5 sec. Then, the network density (ρ_n) is being calculated for each water column in the terrain as in Eq. 6:

$$\rho_n = \frac{N}{A} \quad (6)$$

Where:

N = The number of nodes
A = The area

Forwarding nodes of packets then attach its depth data forwarding directions, NADV (Normalized advance) (Lee *et al*., 2005) status by Eq. 7:

$$NADV = \frac{ADVANCE}{COST} \quad (7)$$

The metrics of cost is calculated with throughput. The intensity region where funneling effect problem occurs is being set up with point to point communication.

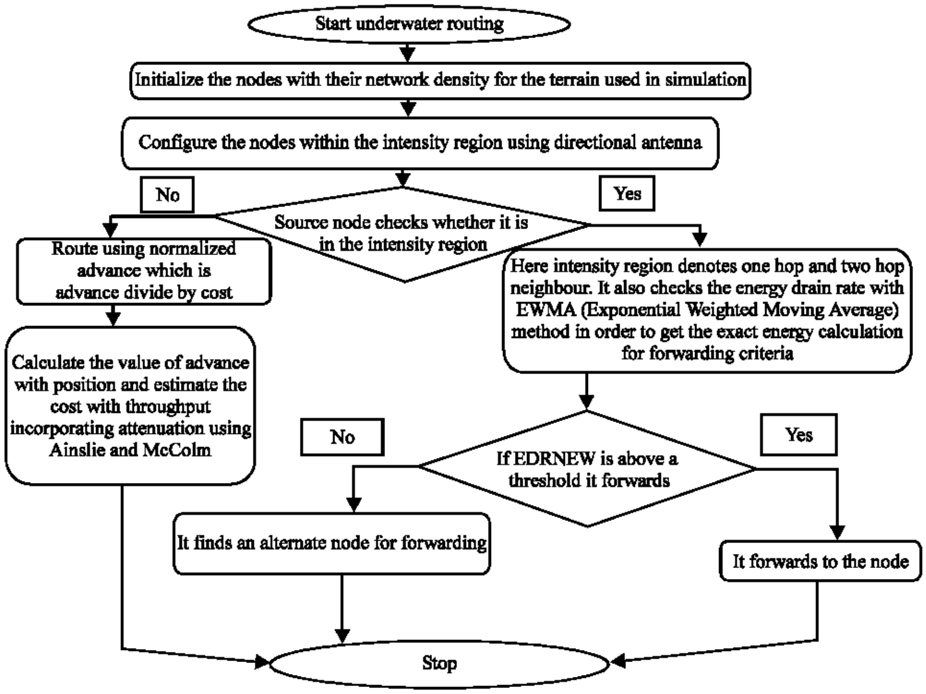

Fig. 1: Describes the methodology for geographical routing with energy drain calculation

The assumption is made such that the intensity region will be nodes that are one hop or two hop regions to the sonobuoy. The Euler's method is used where data are taken at that point at that instance of time. To cover point to point communication, directional antenna is used this antenna that provides longer transmission.

The packet is to be forwarded to its one hop neighbor node with (NADV) routing. It checks the energy drain rate using residual energy of the node is being checked. In order to get precise value an Exponential Weighted Mmoving Average (EWMA) is used similar to that of drain rate calculations of minimum drain rate as in Kim *et al*. (2003).

$$\text{Energy drain rate} = (\text{Initial energy} - \text{Nodes current energy} \tag{8}$$

This value of Energy Drain Rate (EDR) is checked every 5 sec:

$$EDR_{NEW} = \alpha \times EDR_{OLD} + (1-\alpha) \times EDR_{Current\,sample} \tag{9}$$

The value of α (weight factor) is set as 0.7. If the value of EDR_{NEW} is below a predefined threshold it finds an alternate node for forwarding.

If subsequent energy of one hop neighbour is high it sends one Directional Request To Send (DRTS) and receives one Clear To Send (CTS) and communicates data (Ko *et al*., 2008) whereas the other communications is being blocked. Since this work focuses on dense network, there will be a node which will receive the DRTS. The energy drain rate as in is checked when it reaches the two hop neighbours. If it is within the transmission range of sonobuoy it transmits as such. If the distance is out of range transmission it sends two DRTS one to the sonobuoy and other to the one hop neighbour and calculates the third distance using:

Pythagorean theorem:

$$a^2 = b^2 + c^2 \tag{10}$$

For finding the angles: The following trigonometry formulas are used to find the appropriate forwarding angle:

$$a^2 = b^2 + c^2 - 2bc\,\text{Cos}\,A$$

$$2bc\,\text{Cos}\,A = b^2 + c^2 - a^2$$

$$\text{Cos}\,A = \frac{b^2 + c^2 - a^2}{2bc}$$

$$A = \cos^{-1}\frac{b^2 + c^2 - a^2}{2bc}$$

Formula two:

$$b^2 = c^2 + a^2 - 2ac\cos B$$

$$2ac\cos B = c^2 + a^2 - b^2$$

$$\cos B = \frac{c^2 - a^2 - b^2}{2ac}$$

$$B = \cos\frac{c^2 + a^2 - b^2}{2ca}$$

By calculating the angle the proper routing direction can be calculated. It transmits packets and calculates the packet drop rate. Meanwhile it checks for the percentage of channel utilization rate with Eq. 10 and 11 along with the calculation in its upper hemispherical transmission range:

$$\text{Percentage of channel utilization} = \frac{X}{\text{Number of channel}} \quad (11)$$

Where: X is

$$X = \frac{\sum_1^N \text{Duration of time channel is used}}{\text{Simulation end time} - \text{Simulation start time}} \times 100 \quad (12)$$

If the packet drop is high then it checks the channel utilization rate is high and it back off for a while and then routes to its one hop neighbour. Here packet drop rate of the channel is calculated by using the metrics of 1-packet delivery ratio.

When a communication is being established with one DRTS, the receiving nodes send an Omnidirectional Clear To Send (OCTS) and block the remaining nodes (Ko *et al*., 2008) to overcome deafness issues.

Aqua Funneling and Energy Holes Avoidance with Optimal transmission using Directional Antenna (AFEHAODA)

Motivation behind AFEHAODA: The problem with the prior type of protocol is that it does not provide support to multiple interfaces which is available in TENS. Type I Antenna (HYACINTH which could support with five different interfaces) (Ahmed *et al*., 2015). This has been extended in under water sensor networks with proper direction for routing with control packets.

Algorithm: All nodes initialize the surface id and depth. Then, the sonobuoy initializes the position of all nodes with its control packet after every 5 sec. Then, the network density (ρ_n) is being calculated for each water column in the terrain as in Eq. 13:

$$\rho n = \frac{N}{A} \quad (13)$$

Where:

N = The number of nodes

A = The area Forwarding nodes of packets then attach its depth ( ) data forwarding directions, NADV (Normalized Advance) status by Eq. 14:

$$NADV = \frac{ADVANCE}{COST} \quad (14)$$

The metrics of cost is calculated with throughput. The assumption is made such that the intensity region will be nodes that are one hop or two hop regions are affected by funneling effect and energy hole problems.

Before forwarding a packet to its one hop neighbour it checks the energy drain rate EDR_{NEW} as in Eq. 8 and 9 and then decides whether to forward or reroute. If subsequent energy of one hop neighbour is high after exchange of DRTS and CTS it forwards data. Similarly if a packet is to be forwarded to its two hop neighbour it checks the energy drain rate EDR_{NEW}. When the packet is to be forwarded from the two hop neighbour it uses multi-interface support which is available in ns2 and provides better performance metrics as discussed by authors in. It allows funneling nodes nearby to communicate eliminating collision and reduces the processing time with varying power levels. Channel diverse capability in which channels are mutually exclusive which are of node disjoint type is used.

Here, there are five channels. The primary 3 channels are between the 2 hop neighbour and sink. Whereas the other 2 channels are between the 2 hop neighbour and 1 hop neighbour. The source node in its intensity region checks for the nodes within its upper hemispherical transmission range and computes the neighbour node (one hop neighbour) and sonobuoy and sends two DRTS.

If the distance is more power level is high and if the distance is less power level is low. It transmits packets and calculates the packet drop rate. Meanwhile, it checks for the percentage of channel utilization rate with Eq. 14 along with the calculation in its upper hemispherical transmission range:

$$\text{Percentage of channel utilization} = \frac{X}{\text{Number of channel}} \quad (15)$$

where, X is:

$$X = \sum_{1}^{N} \frac{\text{Duration of time channel is used}}{\text{Simulation end time} - \text{Simulation start time}} \times 100 \quad (16)$$

If the packet drop is high then it checks the channel utilization rate is high and routes with alternate channel. The protocol two hop neighbours tries to route directly to sonobuoy if it is within the range of transmission. In the case of two hop neighbor node being out of range transmission it routes to its one hop neighbour only when 3 channels has increased channel utilization rate and packet drop rate. It has increased transmission rate than AFEHADA.

In the case of AFEHOADA rather than using a single channel. Here the number of channels is increased and they are mutually exclusive. That is channel diverse capability is used and if the drop rate is high it terminates the current transmission and switches to the other with multi interface support. Thus the problem of backing up has been eliminated with channel diverse capability.

RESULTS AND DISCUSSION

The simulations were carried out with ns2 simulator. The aquasim patch were underwater, MAC folder (uw_mac) changes had been done in underwater propagation files for development of attenuation calculations using Ainslie and McColm Model with declaration of temperature, salinity, pressure, frequency and pH values. The mobility pattern used was random waypoint mobility model with minimum speed of 0.3 m sec^{-1} and maximum speed 1 m sec^{-1}. The performance metrics was measured at pause time (Euler's approach) (Table 3):

$$\text{Throughout} = \frac{\text{Number of Recieved data fames} \times \text{Data size}}{\text{Simulation Duration} \times \text{Data rate}} \quad (17)$$

The protocol with multi-interface support AFEHOADA was better with throughput denoted by equation 14 than the single channel protocol using AFEHADA Fig. 2. Both the protocols perform better than VAPR:

$$\text{Goodput} = \frac{(\text{Send data} - \text{Re transmitted data})}{\text{Total transfer time}} \quad (18)$$

Table 3: The simulation parameters used in aquasim patch in underwater environment

Protocol used	VAPR	AFEHADA	AFEHAODA
Antenna	Omni directional	Directional antenna at intensity region and omnidirectional antenna in the antenna other area	
Sonobuoy	5		
Number of nodes	100		
Simulation duration	500 sec		
Terrain	1000×1000		
Packet size	512 bytes		
Initial energy	5 J		
Transmission power	1 W		
Reception power	0.01 W		

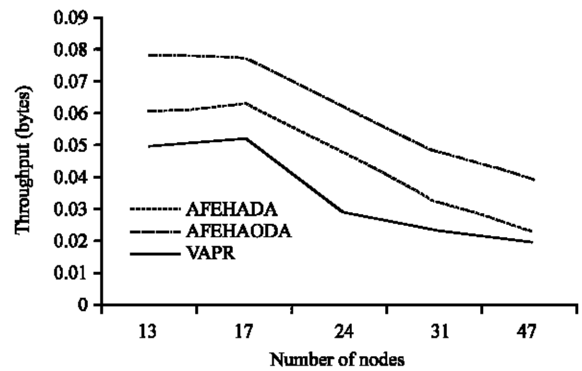

Fig. 2: The number of nodes in the intensity region and its throughput

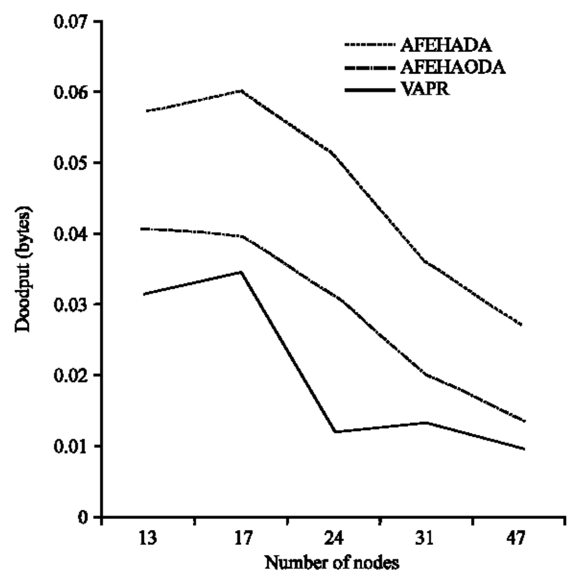

Fig. 3: The number of nodes in the intensity region and its goodput

The goodput performance was measured with Eq. 16 also showed a substantial increase with AFEHOADA than AFEHADA with and both the protocols perform better than VAPR Fig. 3:

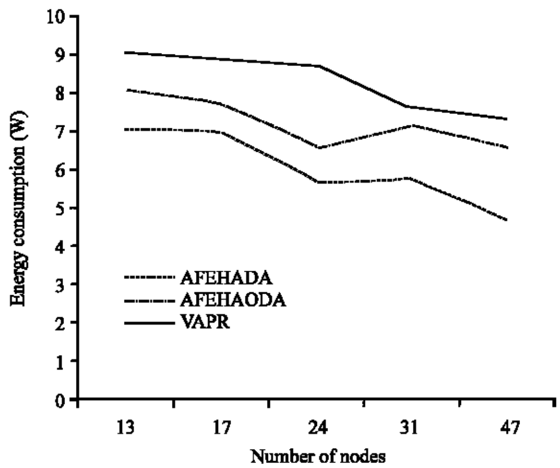

Fig. 4: The number of nodes in the intensity region and its energy consumption

$$\text{Energy Consumption} = \left(\begin{matrix}\text{Initial energy} - \text{Nodes} \\ \text{Current energy}\end{matrix}\right) \quad (19)$$

$$\text{Average energy consumption} = \frac{\text{Total consumed energy}}{\text{Number of nodes}} \quad (20)$$

The energy consumption was found with residual energy calculation as per Eq. 18 and average energy consumption as in Eq. 17. (Fig. 4). The AFEHOADA protocol does not perform better than AFEHADA even with the multi-interface support at those nodes, the reason behind is transmission consumes more energy with the multi-interfaces than in single interface. But the design of AFEHOADA is made such that it avoids energy hole which make the protocol superior. Both the protocols AFEHOADA and AFEHADA perform better than VAPR.

CONCLUSION

It is pertinent that directional antenna is the most suitable to funneling effect and energy holes problem due to its myriad application (congested path avoidance and energy drain issues). AFEHADA which was a single channel protocol avoids energy hole but was susceptible to congested path and has a recovery node or employs backs off procedure or finds a alternate node for routing. Whereas, AFEHAODA was based on channel diverse capability with multi-interface support has higher productivity (throughput and goodput).Simulations were performed with attenuation development for Ainslie and McColm model. Both the protocols were compared with Void Aware Pressure Routing (VAPR) and was better in terms of throughput, goodput and energy consumption.

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