SMART ACOUSTIC SENSOR NETWORK

G.SACHIN SAGAR[1], K. SHRI SAMBAVAN[2], R.PERUMAL[3], N.SARAVANAN[4], N.KANNIYAPPAN[5]

[1, 2, 3] *(Scholar, Electronics &Communication Engineering, GKM College of Engineering & Technology, Anna university, Chennai, INDIA)*

[4, 5] *(Assistant Professor, Electronics &Communication Engineering, GKM College of Engineering & Technology, Anna university, Chennai, INDIA)*

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Abstract: *This article deals with the dual problem of inaccurate localization and navigation of packets in the underwater acoustic sensor network between the anchor nodes. The packet get transmitted to the anchor nodes using two scheme such as collision tolerant scheme (CTS) and collision free packet scheduling(CFS).We are mainly focusing on minimizing the localization time so the coverage area and throughput get increased. In the collision tolerant scheme the anchor nodes work independently .so it consume more energy but CTS provide better localization in a minimum localized time with less complexity. In this Gauss Newton algorithm is employed to the every anchor nodes for the self-localization .Cramer-Rao lower bound value is also estimated for the additional justification.*

Key words: *Acoustic sensor network Collision tolerant, Collision free packet schemes, self-localization.*

1. INTRODUCTION

After the implementation of the autonomous underwater vehicles (UAV) the network is fully paving its way towards the underwater acoustic sensor networks (UASN) .It enable the application such as oceanographic data collection, Tsunami monitoring, disaster prevention ,tactical surveillance etc. In the underwater system every node should transmit it location and time to the neighbor node in the network. Major drawback on the underwater acoustic communication is low data rates and the propagation delay with variable sound speed. The range of GPS signal (Radio Frequency) is low in the underwater, so the underwater acoustic sensor is used as instead. The node location is determined by the time of flight (ToF) and also calculating the average distance between the two nodes. Accuracy factor of the self localization is determined by the number of anchors, position of the sensors node and finger printing is a technique employed to self-localization.

In the underwater system the nodes are arranged in the long base line (LBL).where the transponder is placed on the sea-floor and the underwater sensor communicate with the transponder with the round-trip estimation. In the underwater the master node send beacon signal periodically after the receiving the beacon signal the other anchor node start transmitting the data packets with the previous node. The pros of the algorithm are that reflect the problem faced by the joint node discovery and the collaborative localization without the use of GPS. In this algorithm some anchors are primary seed nodes and necessary sensor nodes are converted to the primary seed nodes, which enhances larger sensor networks. It works on the broadcasting command packets, where the nodes the time of flight. The performance is calculated by set-up time and coverage area, where the collision and shadowing is not taken into the account for the optimum localization. In this system by transmitting "good bye" by the help of the existing method such as MAC protocol it will not perform high effectively while the carrier sense multiple access (CSMA) perform better than the existing protocol.

In the previous study they considered collision-free packet in the UASN for the localization in single-channel (L-MAC) and the multiple scenario's (DMC-MAC).It provide remarkable performance but it need a fusion centre , falls as a major drawback in this protocol. The fusion centre will carry the address of the anchors and decide the time of the data transmission from each other. And additional to that synchronization is needed and uses radio modem as medium. In this paper we are considering the packet scheduling algorithm, it doesn't require the fusion centre and a-synchronization of node is provided, hence the working on the GPS is not difficult. In this system we assume Single hop UASN and they provide half-duplex. The scheduling of packets takes in two scenario's: a collision free packet (CFS),where there is no collision during the transmission and collision Tolerant scheme (CTS) there is some tolerable acceptance of the collision can occur at the sensor node and receive many error-free packets for self-localization.

- The minimum value of the packet loss, collision and localization time is analytically obtained for each sensor nodes on reducing the localization time the dynamic network can be achieved and increases the throughput value.
- The Gauss Newton self localization algorithm is established to every sensor nodes, which contain packet loss and collision.

- Cramer-Rao lower bound is derived to calculate the value of the packet losses and the probability of the self –localization is determined.

2. NETWORK NODES

USAN consists of numerous sensor and anchor nodes. The anchor node shares its location &time for packet transmission with neighboring nodes. The system structure is specified as

- Anchors nodes and sensor nodes are in half duplex.
- They are randomly placed within the coverage are of the network with respective probability density function.
- It is a single hop network
- The transmission distance gives the signal strength and the distance between the anchor and the sensor nodes gives the probability for packet loss.

The localization algorithm for the sensor nodes depends on two algorithms. The sensor nodes find its distance between the anchor nodes via Round trip delay estimation and Time of flight. The algorithm for localization is either *Periodic* or *on demand* basis.

2.1. Periodic Localization

This method may be employed if all the nodes are synchronized with each other. The distance of the sensor node from the anchor is estimated as

$$\hat{d}_{m,j} = c(t^{\wedge R}_{m,j} - t^{T}_{j}) \qquad (1)$$

Where,

c=sound speed,

t^T_j = anchor node's packet transmission time

$t^{\wedge R}_{m,j}$= estimated time at which the packet is received at the sensor node

The estimated time is related with the arrival time by

$$t^{\wedge R}_{m,j} = t^R_{m,j} + n_{m,j} \qquad (2)$$

Where $n_{m,j}$zero mean Gaussian noise .There is is no compulsion for the sensor nodes to be synchronized and so they can find the time difference easily.

2.2. On-Demand Localization

This method applies for both synchronous and asynchronous network nodes. A wake up tone of high power frequency is sent to the anchor node to set it listening mode. After receiving the wake up tone the anchor node sends a localization packet which includes the time$t^{\wedge R}_{m,j}$, at which the wake up tone is received and the timet^T_j at which the localization packet is sent. Considering this the sensor node estimate it's round trip time to the anchor. It is given as

$$t^{\wedge RTT}_{m,j} = (t^R_{m,j} - t^T_m) - (t^R_{j,m} - t^T_j) + n_{j,m} + n_{m,j}$$
(3)

t^T_m = time of transmission of the wake up tone from sensor node to the anchor

Estimated distance is given as

$$\hat{d}_{m,j} = \frac{1}{2} c t^{\wedge RTT}_{m,j} \qquad (4)$$

The sensor node estimates its location without initiating another localization task. The time within the sensor nodes receive K different data packets from K anchors are known as localization time.

3. PACKET SCHEDULING

3.1. Collision free packet scheduling

Collision free packet transmission is discussed below, where a single hop network is established for the sequence of anchor indices, and the each node should transmit the packet after the receiving from the previous one. In additional to that the localization time get reduced after the optimal ordering the sequence, to obtain the fusion centre. If the information is not transmitted then the anchor nodes send the ID numbers. In the case of the packet loss the subsequent anchor will not the time of transmissions. So the anchor node waits for a predefined time till they receive the packet from previous node. The delay time of the j^{th} anchor node (not received a packet from the previous one)can be stated a $t_k + +(j-k)(T p + \frac{D_{aa}}{c})$,Where the k is the last receiving packet at the j^{th}anchor node, t_k is the time of the packet transmission from the k^{th} anchor , $\frac{D_{aa}}{c}$ is the maximum propagation delay between the two nodes, T_p is the packet length, where Ts≈(1/B),number of bits in the symbols b_sTs and guard time as T_g are formulated as,

$$T_p = T_g + (\frac{b_p}{b_s}) \qquad (6)$$

The transmission time of the j^{th} anchor node can be selected as $D_r = D_s$, $t_1 = \frac{d_s}{c}$ in on-demand localization.The value is corresponding to the maximum separated sensor-anchor node pair and D_r=0, t_1=0 in periodic localization, ds=distancebetween the first node and the sensors.$p_l(d_{i,j})$ =probability of the packet loss between the two nodes present at $(d_{i,j})$ meters, the packet loss can be defined as,

$$p_l(d) = \int_{\gamma_0 N_0 B}^{\infty} f(X_0|d)(x)dx \qquad (7)$$

where N_0B is the noise power , γ_0 is the minimum SNR at the received packet, $fX0|d(x)$ is the conditional pdf of the received signal .The average time required to transmit the packet of the j^{th} anchor node is given by,

$$\bar{t_j}=(1-\bar{p_l})\sum_{k=1}^{j-1}\bar{t_k}\,\bar{p}_l^{\,j-k-1}+T_{p(1-\bar{p_l})}+\frac{\bar{d}}{c}-\frac{\bar{d}_{pl}}{c}+(1-\bar{p_l})\left(\left(\frac{D_{aa}}{c}\right)+T_p\right)\sum_{k=1}^{j-1}k\,\bar{p}^{k-1}+(j-1)\left(\frac{D_{aa}}{c}+T_p\right)\bar{p}^{k-1}+\frac{D_r}{c}\,\bar{p}_l^{\,j-1} \quad (8)$$

The average localization time of a collision –free scheme is obtained as,

$$T_{avg}CF=t+T_p+\frac{Dsa}{c} \quad (9)$$

Where the $\left(\frac{D_{sa}}{c}\right)$ **is** added to ensure the Nth node reaches the furthest point in the operating area.

In the best cases, there is loss of packets and the localization time reaches the minimum value,

$$T_{CF}^{low}=(N-1)\frac{\bar{d}_s}{c}+\frac{\bar{d}_s}{c}+NT_p+\frac{D_{sa}}{c} \quad (10)$$

Where, the $\bar{d}_s$ is the average distance between the sensor nodes.

In worst case all the packet get lost between the anchors .the distance between the initiator and the receiving node is high , localization time is high and is given by,

$$T_{upp}^{CF}=NT_p+(N-1)\frac{D_{aa}}{c}+\frac{D_{sa}}{c}+\frac{D_{sa}}{c} \quad (11)$$

Another strategy is that if the probability is above the design value of $\mathbf{P}_{SS,}$ the number of anchor and T_{avg}**CF** also reduces,

$$p_{CF}^{loc}=\sum_{k=K}^{N}\binom{N}{k}p_{CF}^{k}(1-p_{CF})^{N-K}\geq p_{ss} \quad (12)$$

Where the $\boldsymbol{P}_{CF}$=Probability of the transmitted packets are reached correctly to the sensor nodes and it is derived by,

$$P_{CF}=\int_{\gamma_0 N_0 B}^{\infty} f\,x_0(x)\,dx \quad (13)$$

Where $\mathbf{f_{x0}(x)}$ **is** the probability density function of the received signal.

3.2. Collision tolerant packet scheduling

The anchor functions independent to each other in order to avoid coordination among the anchor nodes in the CTS, during the localization period or on receiving a request from the sensor nodes. The packet transmitted from different nodes get collide with each other at the sensor node while transmitting to a common fusion center and the path loss is un-measurable since the location and power control should be known to compensate the path-loss.so there is no power control. The average strength of the received signal is thus different for the different links. The signal received at m^{th} sensor node from the j^{th} *anchor* is given a

$$v_{m,j}(t)=c_{m,j}v_j(t)+i_m(t)+w_m(t) \quad (14)$$

Where $\boldsymbol{v_j(t)}$ is signal transmitted from j^{th} anchor, $\boldsymbol{c_{m,j}}$= channel gain, $\boldsymbol{w_m(t)}$ = additive white Gaussian noise, $\boldsymbol{N_0B}$ is the power and $\boldsymbol{i_m(t)}$ = interference caused by anchors whose packet is overlapped with the desired packets.

$$i_m(t)=\sum_{k\neq j}c_{m,k}v_k(t-\tau_k) \quad (15)$$

Where τ_k =average value of the arrival time of the interfering signal. The interference depends on the SINR value.

$$\gamma=\frac{x_0}{I_0+N_0B} \quad (16)$$

Where $X_0=\left|c_{m,k_j}\right|^2P_0$ is power of the signal with P_0 is the power of transmitted anchor and I_0 total interference power, which is expressed as,

$$I_0=\sum_{i=1}^{q}\left|c_{m,k_j}\right|^2P_0 \quad (17)$$

Where q as number of interferer, $\boldsymbol{k_i}$ index of the $\boldsymbol{i^{th}}$interfere*r*. The signal power is given by,

$$\left|c_{m,j}\right|^2=a_{PL}^{-1}(d_{m,j})e^{g_{m,j}}\left|h_{m,j}\right|^2 \quad (18)$$

Where,

$g_{m,j}\sim N(0,\sigma_g^2)$ Models large scale log-normal shadowing**,** $h_{m,j}\sim CN(h,\sigma_h^2)$ Models small scale fading and a_{pl} is the attenuation of the path loss is formulated as,

$$a_{PL}(d_{i,j})=\alpha_0\left(\frac{d_{i,j}}{d_0}\right)^{n_0}a(f)^{d_{i,j}} \quad (19)$$

Where α_0 is a constant, n_0 path loss exponent, $\boldsymbol{a(f)}$ is the coefficient of frequency –dependent. The pdf of the interference is given by,

$$f_{l_0}(x) = f_{x_0}(x) * f_{x_0}(x) * \dots * f_{x_0}(x). \quad (20)$$

Assume that the anchor fades independently, when they are transmitted from the same node and the probability of the packet received at the transmission time T_t is given by,

$$p_{CT} = 1 - e^{-p_s \lambda T_T} \quad (21)$$

The probability that the sensor node equip the self-localization using N anchors can be obtained as,

$$p_{CT}^{loc} = \sum_{k=K}^{N} \binom{N}{K} p_{CT}^{k} (1 - P_{CT})^{N-K} \quad (22)$$

From the above equation the number of nodes N, probability of successful self-localization P_{SS} .Minimum localization time can also be derived from the above equation T_t.In the collision free packet the additional of Tof, maximize the propagation delay between the sensor nodes to obtain minimum. So the obtained value gives the minimum localization time for the collision – tolerant scheme.

4. LOCALIZATION TECHNIQUES

. The localization of sensor node is done by the K different data packets received from the anchors. The sensor node may also receive more than K data packets also some replicas like q_j, from anchor j, where j = 1, 2, 3….N. In collision free scheme q_j is either zero or one but in collision tolerant scheme q_j is more than one. Packets that are correctly received helps in estimating the distance between sensor node and the anchor node. Thus localization is proposed by certain algorithms

4.1 Localization Algorithm

The anchor sends the data packet to the sensor node which has Q measurements which is contaminated by noise. Its power is related to the distance between the sensor and the anchor. The relation between the j^{th} anchor's measurement and the sensor position is given as

$$\hat{t}_l = f(x) + n_1 \quad (23)$$

Where n1 is measurement of noise

$$f(x) = \frac{1}{c} \|x - x_j\|_2 \quad (24)$$

Where $x_j = j^{th}$,
Anchor position. Therefore measurement is given by

$$Q = \sum_{j=1}^{N} q_j \quad (25)$$

q_j=number of measurements.

Regarding CTS q_j is a Bernoulli random variable and in CFS q_j is a Poisson random variable.
The success probability of CTS is

$$P_j^1 = P(q_j = 1) = 1 - pl(d_j) \quad (26)$$

d_j = Distance between the sensor node and the j^{th} anchor.
The distribution of Poisson random variable is

$$P_j^n = P(q_j = n) = \frac{(p_s \lambda T_T)^n}{n!} e^{-\lambda T_T p_{s|d}^j} \quad (27)$$

Where $p_{s|d}^j$ is the conditional probability of a sensor node to receive a packet from known anchors .The measurement errors are independent and can be calculated by Gauss Newton algorithm.
The algorithm states that
η Controls the speed of the convergence

$$\Delta f(x^{(i)}) = \left[\frac{\partial f_1}{\partial x}, \frac{\partial f_2}{\partial x}, \dots \frac{\partial f_Q}{\partial x}\right]_{x=x^i}^T \quad (28)$$

is the gradient of the vector f

$x^i$is the estimate in i^{th} iteration.

4.2 Cramer-rao bound

The CRB which is a lower bound on any unbiased estimator is defined by Fisher information matrix. It is the information of the random variable ^t carries with the pd it depends.

$$I(x)_{i,j} = -E\left[\frac{\partial^2 \log h(t^{\hat{}}x)|x}{\partial x_i \partial x_j}\right] \quad (29) \quad ($$

x=location of the sensor node.
The elements of the FIM contaminated by Gaussian noise is shown as

$$I(x)_{i,j} = \frac{1}{p^{loc}} \sum_{qN=0}^{Q_N} \dots \sum_{q2=0}^{Q_2} \dots \sum_{q1=0}^{Q_1} \dots (30)$$

Thus collision free scheduling has $\sum_{k=K}^{N} \binom{N}{k}$ states while for collision tolerant scheme has countless.

5. ENERGY CONSUMPTION BY TWO SCHEMES.

The energy consumption of collision tolerant scheme is higher than collision free scheme. In CFS the higher index anchor consumes more energy. The average energy consumption is

$$E_{CF}^{avg} = NT_pP_T + \sum_{j=1}^{N} t_j P_L \quad (31)$$

In CTS the anchors transmit packets per second. The average energy is

$$E_{CT}^{avg} = \lambda T_T NT_pP_T \quad (32)$$

6. NUMERICAL RESULTS

To illustrate the results, the2D image of the operating area of length D_x and width D_y is considered with uniform anchors and sensor nodes. The number of the anchor and the sensor nodes can vary .So the f_D (d) n= $g_D(d)$, which can be obtained by,

$$f_D(d) = \frac{2d}{D_x^2 D_y^2}[d^2(\sin 2_{\theta_e} - \sin 2_{\theta_s}) + 2D_xD_y(\theta_e - \theta_s) + 2D_x d(\cos\theta_e - \cos\theta_s) - 2D_y d(\sin\theta_e - \sin\theta_s)] \quad (33)$$

The θ_e and the θs are related to d.

By setting the value of σg=0 in the simulation the successful self localization can be obtained in the CTS. The energy consumption can be reduced by reducing the value ofλ.

In the collision tolerant system the rate of the growth is higher for the minimum localization time and the operating area plays a vital role in the performance of the CFS than the CTS performance.

The accuracy is mainly depends on the (ToF)and the anchors constellation. It is observed that CTS has minimum localization error compared to the CFS, because in the CTS there is a probability of receiving the multiple copies of same packet, hence value the error can be reduced.

7. DATA TRANSMISSION IN NODES

7.1 Periodic Transmission

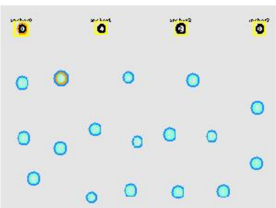
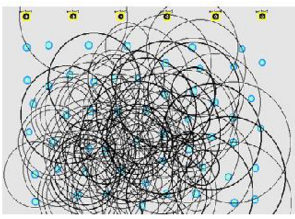



Fig 1: Initialization of nodes Fig 2: Echo Reception in nodes.

The anchor and the sensor nodes gets initialized .The anchor node sets data packet to the sensor nodes. Data gets transmitted only through the shortest path communicating to the neighboring nodes Thus the entire system gets activated. Fig 1 shows the nodes gets initiated on periodical basis . The reception of echo signal along the entire system is shown in Fig 2.Thus in periodic transmission the anchor node initiates the data transmission.

7.2 On-demand Transmission

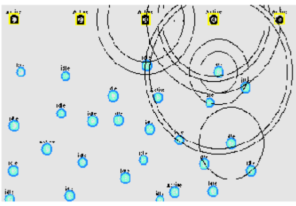
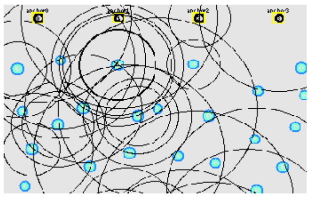



Fig 3: Initialization of nodes Fig 4: Echo reception in nodes

The on-demand transmission follows the same principle but sensor node gets initialized first. Fig 3 shows the transmission of the packets from the sensor node to the anchor nodes. The echo received is shown in Fig 4 is transmitted. Thus the system communicates in on-demand basis.

8. PACKET LOSES DURING TRANSMISSION

8.1 Periodic transmission

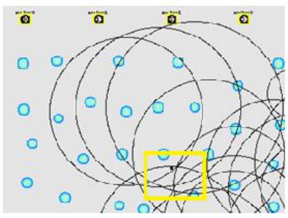
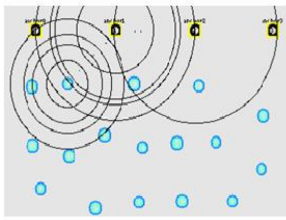
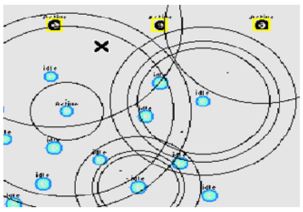



Fig 5: Packet loss Fig 6: Packet transmission

In the fig (5) & (6) describes the packet transmission periodically between the anchor nodes and the sensor nodes at regular time interval. During the packet transmission the packet gets lost .so the system gets in- efficient, the performance level decreased .The packet lost in the periodic mode is marked as yellow box in the fig (5).

8.2 On-demand transmission



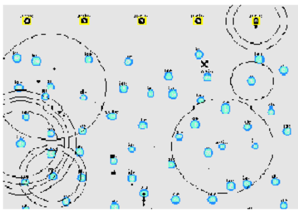


Fig 7: Packet transmission Fig 8: Packet loss

In this fig it describes the packet transmission from the active node to the anchor anode only on the demand basis. so the efficiency increased and the power consumption get decreased and the transmission and the packet loss are shown.

9. CONCLUSION

On considering two scenarios on the packet scheduling in UASN: collision free scheme and the collision tolerant scheme. In the collision free packet scheme the time of the packet transmission is set in such a way that the collision will not occurs. In the collision tolerant scheme in order to minimize the probability of collision the Gauss Newton algorithm is proposed and the Cramer-Rao lower bound value is also calculated as benchmark. The time required for the localization reduced when the ratio of the packet length and the maximum propagation delay is low and the packet loss is not close to zero. The major advantage is implementation is simple and the anchor works independently and no fusion centre is required. The localization accuracy is high in CTS than the CFS.

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