Underwater Distributed WSN Data Gathering Algorithm for Multi-Source Data Fusion

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***Abstract* — In view of the long time delay in real-time data collection in underwater distributed sensor networks, and in order to ensure the safety and accuracy of sensing data, this paper proposes a wireless sensor network data gathering scheme for underwater distributed data fusion. The algorithm firstly sets up a data aggregation tree based on maximum independent sets, and each node carries on data gathering according to the data aggregation tree hierarchy. In the constructing procedure of data aggregation tree, for two control points two-hops apart, a further two-hops apart two control points are added into the data aggregation tree through the control point closest to Sink. The application layer uses credibility evaluation and reliability allocation method to calculate the fusion result for decision-making, and through the reliability allocation of evidence function means to make the fusion result closer to the real value. The simulation results show that the proposed data fusion scheme has obvious advantages over the same kind of LEACH protocols in aspects of ordinary node energy consumption and fusion precision, with the data aggregation latency generated by this algorithm is far lower than the existing algorithms. The scheme is effective and feasible for underwater node data aggregation.**

Keywords - distributed network; sensing network; multi-source data fusion; data aggregation; underwater network

I. INTRODUCTION

Ocean is rich in resources and vast space, is an important base for human subsistence and realizing the sustainable development of the society. With the exploration of ocean, underwater sensing networks are drawn more and more attentions. Due to the special underwater environment, network data collection is the basis and premise of the whole network management system, network management system through the data collection to obtain the relevant information of the managed device, and provides them for each functional module after processing, thus to realize the effective real-time management of the entire network. In actual network, network management and background flow are sharing network bandwidth. In order to reduce the impact of background flow, network management bandwidth should be limited in 5% of minimum network bandwidth. And with the increasing of network scale, the equipment quantity has increased dramatically, the existing network data collection system is facing problems such as long collection period, heavy management burden, occupied too much network bandwidth, low efficiency, there are many in-depth researches on how to obtain real-time and reliable network state information with minimum network communication costs both at home and abroad. Although these can effectively reduce the communication traffic of data collection, but when the collection nodes quantity is increased or network congestion, which will aggravate the burden of management station, extend the time of collection, do not have good scalability. The emergence of hierarchical distributed network management technology has solved the problems in centralized data collection, thus improve the efficiency of the collection, but using a random sequence of acquisition strategy, it still happens network node failure or congestion that will decrease the efficiency of hierarchical distributed data collection algorithm. In recent years, wireless sensor network (WSN), because it can improve the ability of human to obtain and control the information, thus is drawn people's attention, and the research on sensor used in underwater environment of underwater sensor networks (UWSN) has also showed a trend of rapid growth. The unique characteristics of underwater sensor networks make traditional land sensor network protocols exposed many malpractices underwater, routing protocol is one of the major problems required urgent solution in underwater sensor networks. This paper proposes a multi-source data aggregation scheme based on hierarchy of underwater sensor networks. Before perform routing nodes, it needs to obtain the position and hierarchy information in advance, this can be done through network initialization.

II. UNDERWATER DISTRIBUTED WNS NETWORK MODEL

A. Distributed System Model

Hierarchical distributed model is proposed to solve the problems in centralized model, figure 1 shows a hierarchical distributed model, which is composed by three layers of structure of center manager - domain first - managed device. The network is divided into multiple regions to realize distributed collection, each region is distributed a domain first that is responsible to collect the network information of the equipment in this region. Each domain first completes the collection task distributed by center manager independently, through collaborative communication to realize the effective management of network as a whole. Domain first shielded the details of intra-domain collection to central manager, and center manager is only responsible for data collection of

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node of domain first. In theory, this mechanism reduces the burden of the central manager, simplifies the data collection framework, and solves bottleneck problem in the application of centralized acquisition model in large-scale network.

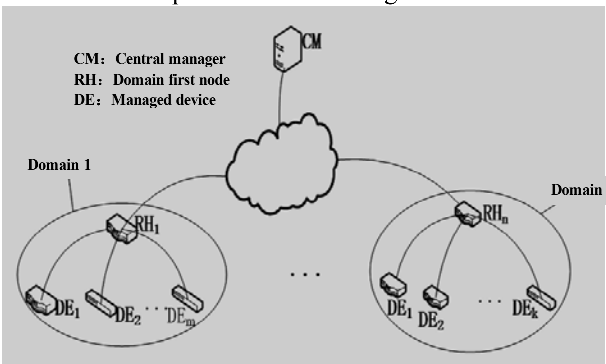

Figure 1. Hierarchical distributed model

There are many methods for zoning of hierarchical distributed network, and different application requirements can adopt different standard divisions. In order to simplify intra-domain topology structure, and achieve rapid domain topology discovery, this paper uses layer 3 switches based on the core to divide the network. Within the domain, the domain first is the key node to carry on intra-domain collection and inter-domain cooperative communication, which is the core of the entire domain, once the domain first fails, and will lead to the failure of the whole domain collecting function. When the domain first node is failure, it needs to use domain first election algorithm to choose in the domain again, so as to realize continuous data collection. Literature studies a kind of group first election algorithm based on network management of agent group, according to the load priority of nodes in domain to conduct domain first election, and have a certain tolerance.

B. *Underwater Sensor Network Model*

Considering the underwater sensor network scenario as shown in figure 2, all user nodes are deployed in a circular region with sink node as the center, and radius of r, which only carries on single hop communication with the sink node. In appointment stage sink node receives only user's booking package, don't reply one by one for each booking package, at the last minute of appointment unity to reply all the user an appointment by the sink node broadcasting, and publishing the allocation result of channel, to realize multiple users within the same period of time. In the process of sending booking package, sink node remains at receiving state, the existence of underwater long propagation delay offers a chance for time and space multiplexing for sending booking package. Not only that, the reservation multi-access protocol based on compression awareness is due to the diversity of each user, avoids the case of sending RTS control packets repeatedly without response caused by poor channel quality, make the best use of the limited communication resources, further improve the utilization rate of the channel.

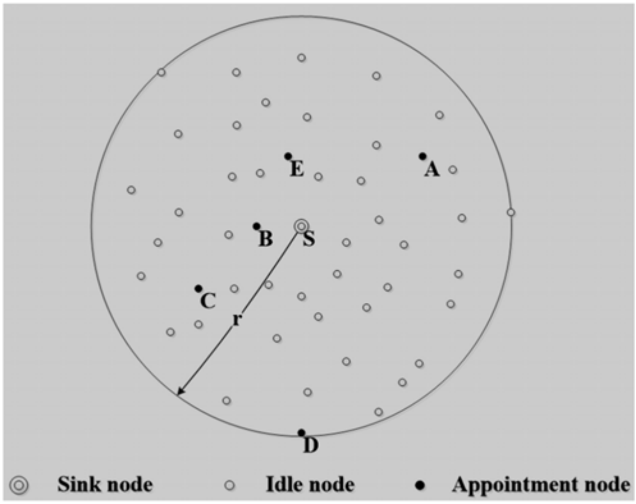

Figure 2. Underwater sensor network scenario

III. MULTI-SOURCE DATA AGGREGATION

A. *Data Aggregation Algorithm*

Algorithm 1 obtained domain collection list PollList

Input: Set Apset, Bcset, Ebcset
Output: domain collection list PollList
Initialization set Apset, Bcset, Ebcset are empty, where Apset is key note set; Bcset is node set of double-connected components $Bcset = \{Bcset_i \mid i = 1, 2...n\}$, where n is the number of double-connected component in domain; Ebcset is the edge set of double-connected component, $Ebcset = \{Ebcset_i \mid i = 1, 2...n\}$, where, n is the same as above.
In domain, according to Tarjan algorithm[16] by the depth-first search Tree (r) to get Apset, Bcset, Ebcset, respectively, and running Tarjan algorithm periodically to update a set.

```
    for i=1;i<=n;i++
      if node u belongs to Apset and is the root
          node of Bcset_i
        PollList = PollList ∪ {u} ;
        Delete all edges related to node u ;
          While Bcset_i − {u} ≠ ∅
          Select node v ∈ Bcset_i − {u} ;
            if v do not have any ancestor
            PollList = PollList ∪ {v} ;
              Delete all edges related to node v ;
          Endif
        Endwhile
      Endif
Endfor
```

Algorithm 2 dynamic data collection algorithm of topological order domain based on node.

Input: domain collection list PollList

Out put: Next domain collection list PollList

Setp1: Domain first receives collection request from central station, generates the corresponding function of mobile Agent. Agent collects data of managed device in domain successively according to the sequence of this collection list PollListk, and in the collection process it dynamically modifies the collection list according to the real-time changes of network.

Step 2: When the mobile Agent have timeout during data collecting on managed device i, check whether i is the root node of set Bcseti(i=1,2…n) root node or whether belong to set Apset. If i belongs to set Apset, then check whether i is root node of Tree(r) r, if $i = r$, the managed device i is added to the next collection list PollListk+1, then the collection is end. If $i \neq r$, delete i and all nodes in set Bcseti with i as the ancestor from the current collection list. If the deleted node exists root node of set Bcsetj ($j \neq i$)or key nodes, then delete Bcsetj from the current collection list.

Step3:when data collecting is proceeding normally, and collecting node has no timeout, then estimate the node: if the node is the key node, then add all successor nodes with node as root node in double-connected components to the next collection list. If the node is not the key node, add all adjacent nodes to the next collection list.

Step4: If the current collection cycle is Rk, if the node $p_i\,(i = 1, 2...m)$ is timeout in collection cycle Rk-2, while not timeout in collection cycle Rk-1, add all nodes p_i to the current collection list for data collection.

B. Data Fusion Process

Cluster nodes in the cluster periodically sends inquiry message $MSGREQ$ to other member nodes for synchronization time, within a sampling cycle t_i , member node A_i (vehicles or facilities at the side of the road) send response message REP_i to cluster head, the formalized description of message model is as follows:

$$m_i = MSG\_REP \,||\, D_\tau \,||\, SN_A \,||\, data \,||\, Pos \,||\, sensid \,||\, Token$$

D_τ : lead code of m_i reflects the data type sensing by node A_i and are used for deducing actual source data to distinguish the lead code of other data packages.

SN_A : the ID of sensing node A_i .

$data = E(\tilde{d}_{sens}, K_{A_i,BS})$, where, $K_{A_i,BS}$ is the symmetric key for protecting sensing data between A_i and BS 之, $\tilde{d}_{sens}$ is the actual source data sensed by A_i , including the supporting degree to this data value.

Pos : distributed grid coordinate (x, y) , describes the geographic position of information source node, used for target positioning[11].

$sensid$: when the mark of current data package, differs from different message sent by the same sensing node. $sensid = F(sensid') \bmod \mathrm{M}$ function F is monotone increasing function in expression, $sensid'$ is the mark of previous data package.

$Token$: message identification domain, $Token = SIG(D_\tau \,||\, SN_A \,||\, data$ $||\, Pos \,||\, sensid, K_{A_i\_TP})$, where, SIG is the digital signature of node A_i , $K_{A_i\_TP}$ is the private key of A_i used for identification, is distributed by AC of network layer.

In the interval Δt , all sensory data from gathering location or forward transmission through intermediate nodes to the cluster head nodes. In the smart distributed environment, sensor node can obtain a variety of data (for example, air flow, temperature, humidity, etc.).Value in a distributed network in the territory said radius is centered and parameter range of perception, within the scope of the other nodes will probably get the same data. Therefore, introduction and parameter can avoid the same data fusion in multiple groups, forming the redundant data sets.

Assumed a set of aggregated data is composed by l different messages, cluster head A_{head} fused $data$ and Pos domain value of l messages, generate new message m_{aggr} and send it to base station, message mode formalized description as follows:

$m_{aggr} = MSG\_REP_{BS} \,||\, SN_{head} \,||\, data_{aggr} \,||\, Pos_{aggr} \,||$ $time_{stamp} \,||\, Token' \,||\, IdList$, where,

SN_{head} : ID of cluster head A_{head} .

$$data_{aggr} = \sum_{i=1}^{l} m_i.data$$

$$Pos_{aggr} = (\frac{1}{w}\sum_{i=1}^{l} w_i m_i.Pos.x, \frac{1}{w}\sum_{i=1}^{l} w_i m_i.Pos.y)$$

(w_i is the D_τ domain data length of message m_i , $w = \sum_{i=1}^{l} w_i$.)

$time_{stamp}$: timestamp, fusion data id classified by accurate $time_{stamp}$ and Pos_{aggr} .

$Token'$: certification mark, $Token' = SIG(SN_{head} \,||\, data_{aggr}$ $||\, Pos_{aggr} \,||\, time_{stamp} \,||\, IdList, K_{Ahead\_TP})$, K_{Ahead_TP} is the private key of A_{head} used for identification.

$IdList$: indicates the order of passing message source in original data aggregation process. $IdList = E(SN_{head} \,||\, SN_{A1} ... \,||\, SN_{Ai} ... \,||\, SN_{AN}$, $K_{Ahead,BS})$, $K_{Ahead,BS}$ is the symmetric key for protecting fusion data privacy between A_{head} and BS .

Base station verifies the received message m_{aggr} . If verification is successful, then accept the data and submit it to the fusion center application layer for processing. Otherwise, then abandon m_{aggr} update credibility of related nodes.

C. The Calculation And Evaluation of Fusion Results

Evidence function is the theoretical basis of evidence, it defines a evidence function m for each evidence to judge events, the evidence function maps U to [0, 1], namely $\mathrm{m}: 2^{\Theta} \longrightarrow [0,1]$. If A is non-zero evidence function value, $\mathrm{m}(\mathrm{A})$ is defined as the supporting degree of function m to A . It can be known from definition1 that $\mathrm{m}(\phi)=0$, $\sum_{\mathrm{A}\in 2^{\Theta}} \mathrm{m}(\mathrm{A})=1$. In the case of multiple sensor data, each data source according to their own definition of evidence function m_i , to make judgement in the same recognition framework respectively, and then effectively merged by the evidence combination rule.

This paper introduces the probability distribution method based on credibility. Set the credibility of data source node r_i be initialized to 5, every time when the test results of source node are consistent with the application layer, credibility plus 1, or minus 1. Then make function transformation on r_i to define weight coefficient w_i as follows:

$$\begin{cases} 0, r_i \le -g \text{或} \alpha_i \le \lambda_0 \\ w_i = \dfrac{r_i + g}{\max(r_i) + g}, r_i > -g \text{且} \alpha_i > \lambda_0 \\ \alpha_i = \dfrac{N_{success}}{N_{total}} \end{cases} \quad (1)$$

Where, $\max(r_i)$ is the maximum r_i in history record of this region, g is constant coefficient, take $g=5$. α_i is the detection accuracy of source node A_i , that is the proportion of the previous N_{total} test results of A_i consistent with application layer $N_{success}$.

When there are n data sources, to obtain the Belief function $\mathrm{Bel}_i(\mathrm{A})$: of source node A_i to evidence A by equation (1)

$$\begin{cases} \mathrm{Bel}_i(\mathrm{A}) = \mathrm{m}_i'(\mathrm{A}) = w_i \mathrm{m}_i(\mathrm{A}), \mathrm{A}\in\Theta \\ \mathrm{Bel}_i(\bar{\mathrm{A}}) = 1 - \mathrm{Bel}_i(\mathrm{A}), \bar{\mathrm{A}} = \Theta - \mathrm{A} \end{cases}, 1 \le i \le n \quad (2)$$

Set I is the maximum subset of event setup in U , by equation (2), the belief function of n data sources merged, and update the belief function according to equation (3):

$$\begin{cases} \mathrm{Bel}(\mathrm{B}_i) = \mathrm{m}_1'(\mathrm{A}_j) \oplus \ldots \oplus \mathrm{m}_n'(\mathrm{A}_j) = k \sum_{\mathrm{A}_1 \cap \ldots \mathrm{A}_p = \mathrm{B}_i} \prod_{i=1}^{n} \mathrm{m}_i'(\mathrm{A}_j) \\ k = [\sum_{\mathrm{A}_1 \cap \ldots \mathrm{A}_p = \phi} \prod_{i=1}^{n} \mathrm{m}_i'(\mathrm{A}_j)]^{-1} \text{且} k < 1 \end{cases} \quad (3)$$

It is known that B1, …Bm are mutually exclusive events, then we have:

$$\mathrm{PI}(I) = 1 - \sum_{\mathrm{B}_1 \cup \mathrm{B}_2 \cup \ldots \mathrm{B}_m = \bar{I}} \mathrm{Bel}(\mathrm{B}_j) \quad (4)$$

When $\mathrm{PI}(I)$ is less than critical value η_0 , execute decision H_0 , otherwise execute H_1 . It can be seen from new evidence function that, when weight coefficient of data source A_i $w_i < 1$, the supporting degree of A_i to evidence A is decreased substantially, while the supporting degree to I $(\mathrm{A} \notin I)$ is increased. After multiple cycles of sampling, if the credibility r_i of A_i is higher, then the generated weight coefficient w_i is more close to 1, otherwise close to 0. Once the evidence function $\mathrm{m}'(\mathrm{A})$ is close to 0, it indicates the ignoring degree of the evidence is raised, and supporting degree on events is decreased. So it forms the reliability distribution of evidence function through credibility evaluation, weakened the influence of fusion results by low reliability of dishonest node evidence.

IV. EXPERIMENT AND SIMULATION

This section uses the simulation to verify the performance of the proposed multi-source data aggregation scheme based on distributed sensor network (CS) in underwater sensing network, and compared with the traditional RTS/CTS schemes. The main parameter settings in simulation process are as follows: the total number of nodes in network (users) is 100, control packet length is 8bit, data packet length is 256bit, data transfer rate is 2kbps, communication radius is 600 m, sound velocity is 1500 m/s. Figure 3 shows that, under the above two kinds of multiple access process, compared the time required to complete the same multiple users information transmission. CS scheme makes an appointment of multiple users at the same time, and RTS/CTS scheme requires each user makes channel appointment alone, and each user in the data transmission includes propagation delay, so as the increase of the number of appointment users *n*, CS scheme needs far less time than RTS/CTS scheme. To be sure, when the appointment user number is less (for example, only one user makes channel appointment), the time needed for CS scheme is higher than the RTS/CTS scheme, this is because in the simulation, it sets 5×*Td* as channel appointment time in CS scheme, in the case of user number is less, this will lead to a relatively higher latency.

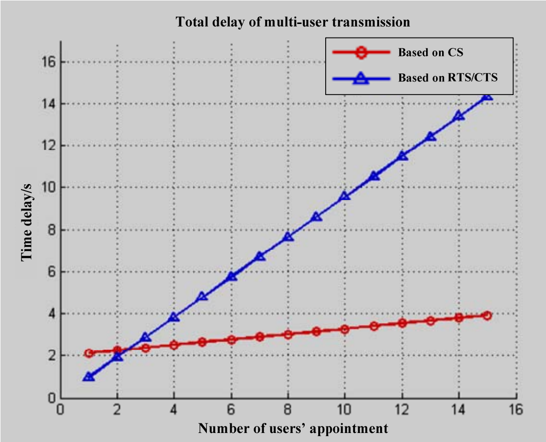

Figure 3. Total delay of multi-user transmission

In the process of the whole communication, and the meaningful part to the user is the data transmission stage. In a working period, the user wants shorter appointment time and longer data transmission time, while the proportion of the data transmission time in one working period determines the efficiency of data transmission. Figure 4 shows the conditions f different users and packet length, the curve of data transmission efficiency changes over the change of the communication radius. It can be seen from the figure, communication radius increasing will make the maximum propagation delay *Td* grown, appointment time increased, and data transmission efficiency declined.

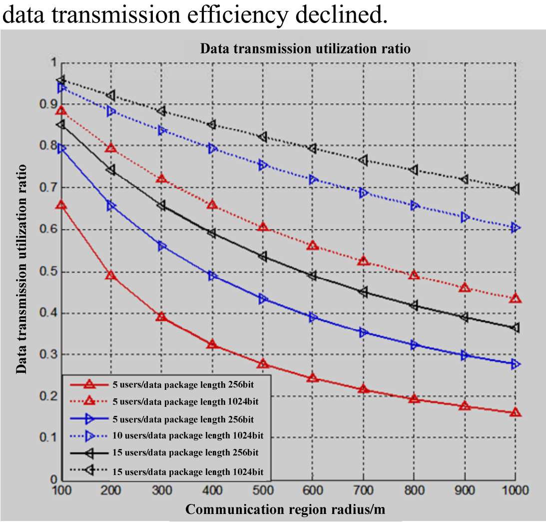

Figure 4. Data transmission utilization ratio

System throughput is rely on data transmission, indicates the number of bits per second. With the increase of bandwidth, throughput of the system is improved. And at the same time it can be seen that CS scheme is better than RTS/CTS, and as the increase of the number of user appointments, CS scheme throughput will be further improved, as shown in figure 5. In addition, the increase of packet length can also improve the system throughput, as shown in figure 6.

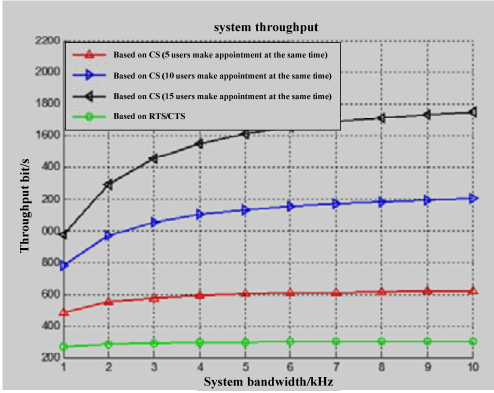

Figure 5. system throughput

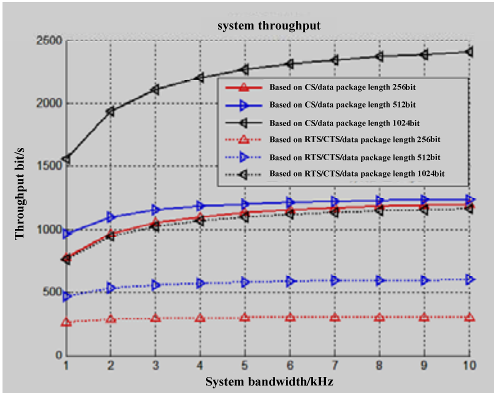

Figure 6. system throughput

A total of 200 cycles are carried on in this experiment, it is selected energy consumption and fusion precision as the index of performance comparison. Because in the proposed scheme, the cluster head is a fixed facility designated by the base station, and each cluster member only needs to send one message per sampling cycle to complete information fusion of each source node. The energy consumption of the cluster members have significantly improved compared with LEACH protocol. It can be seen from the figure 7, for LEACH protocol, as early as the 110 cycle of experiment, in addition to the fusion node, the average energy consumption of ordinary node is 0.7J, and then the proposed scheme is only 0.3J. When the experiment is performed to 180 cycles, LEACH network is almost paralyzed, then the proposed scheme is more than 0.6J. Because the cluster head and base station are all road fixed facilities, the energy consumption problem is much smaller than ordinary nodes.

It can be known from figure 8 (a) that, due to LEACH protocol has no consideration on the attack from inner network, and the same kind of aggressive behavior happened inside the network, the proposed scheme with the aid of lead code and integrity verification are much higher than the fusion precision of LEACH protocol. When the experiment performed to 200 cycles, fusion precision of LEACH protocol has been dropped below 85%, while the proposed scheme is still maintained at 95% and above. Figure 8(b) shows the fusion precision change contrast of two kinds of schemes with the increase of distrust behavior probability of source node. Fusion precision will be influenced by bad data and sensor error, and the distrust behavior namely data sent by the source node is inconsistent with actual value. LEACH protocol only check the property of output data, without considering the reliability evaluation of the node own attributes, and the proposed scheme is based on the assessment of source node credibility to conduct data fusion for the redistribution of the reliability. Even if the number of error sensor increases can still maintain higher fusion precision in network. For example, when distrust probability is 40%, the precision of proposed scheme is 83%, while the precision of LEACH protocol is only 41%. This shows that the proposed scheme has stronger robustness in the process of data fusion.

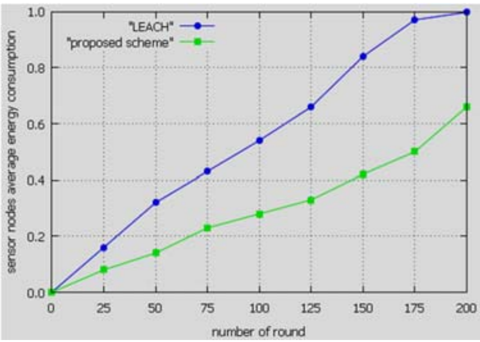

Figure 7. Ordinary node energy consumption comparison

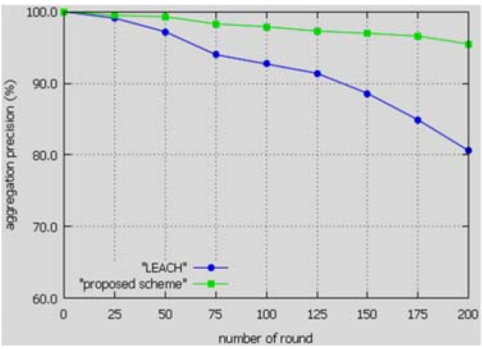

Figure 8. Fusion precision comparison (a)

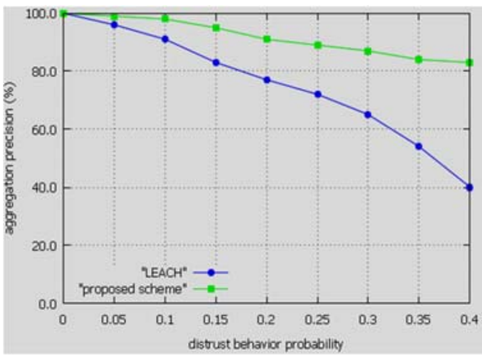

Figure 8. Fusion precision comparison (b)

V. CONCLUSION

The safety data fusion of the wireless sensor network has been received extensive attention of the researchers both at home and abroad. In the process of data fusion how to give consideration to both security and practicability has become a key topic in this research field. This paper proposes a multi-source data aggregation scheme for underwater distributed sensor network nodes, which is used for multi-source data fusion and management in underwater distributed sensor networks. The scheme is combined with the mainstream network structure of sensing layer of current underwater distributed sensor network and the time-space characteristics of multiple source information, increases corresponding data field in message format, and through parameters as lead code, message authentication, etc. to ensure source node packet is effectively and reasonably fused and transferred. The application layer is based on credibility evaluation of each source node to generate evidence of decision-making. The simulation results show that, compared with the proposed scheme, LEACH protocol can effectively reduce the network energy consumption, and can still guarantee the authenticity of the data fusion under the attack of some distrust nodes. The next step will be the further research on optimization problem of routing selection on the basis of this scheme.

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