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Research Article

MCL-A Strategy for Estimating Node Transmission Area in Wireless Underground Networks

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Abstract: Wireless Sensor Networks are designed to detect underground abnormal conditions. Many protocols use distance between the nodes as one of the criteria for multi-hop communication in the network. Node Transmission Area (NTA) helps in predicting the location of the nodes and the distance between the nodes in many power optimization protocols. In this study, Multi-hop Communication with Localization (MCL), a strategy to localize and route information to nodes present in such areas by determining angles and distances of consecutive nodes hop by hop towards the Base Station is proposed. Initially there is a group of nodes deployed in the underground areas all of which bound to a Sink that is further connected to the Base Station. It is possible to locate all the nodes through GPS which can be used as a reference in the worst case scenario by the Base Station. The Sink node has a NTA within which a node can be directly recognized by the Sink node otherwise it finds the target node through the intermediate nodes. In this case, it can be concluded that MCL outperforms DV-hop in time and distance measurement by performing of higher throughput by taking lesser time for data transmission for locating the target node. Simulation analysis is performed in the network simulator to verify the computational method proposed.

Keywords: Base station, localization, multi-hop communication, node transmission area, underground, wireless sensor networks

INTRODUCTION

Wireless Sensor Networks have been used in a many areas right from domestic to industrial areas. Industrial Monitoring and Control have found the applications of wireless sensors very productive. In contrast to this, subterranean areas have been attacked by terrorists in the recent past which have exposed the vulnerability of underground areas. After the London Underground explosion (2005), the usage of WSNs underground has been implemented and is still under current research. There is absolute need to localize and route information through the wireless nodes present in subterranean areas. Hence the need to monitor underground areas has increased greatly. Most wireless communication is hardly possible due to the difficulty in the penetration of wireless signals in underground areas. However, this challenge needs to be overcome by the co-operative process of the underground sensors operating together in a network (Fig. 1).

A number of localization methods are available to detect and localize target nodes in the literature. However, there is the need to investigate techniques that can provide greater accuracy in localizing wireless nodes while communication is performed as well. Beacon based communication can be performed to efficiently localize and communicate with nodes in the network. Methods to perform localization exist in the literature that can provide more than 50% accuracy. However, this is a different approach that explores to send data with greater efficiency wherein localization is an important subpart.

Fig. 1: Usage of wireless underground sensor networks for agricultural monitoring

In this study, a protocol that can efficiently localize and facilitate communication in the wireless underground sensor networks is proposed, simulated and validated.

LITERATURE REVIEW

Bahl and Padmanabhan (2000) proposed that each non-anchor node, unaware of its location, uses the

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signal strength measurements it collects stemming from the anchor nodes within its sensing region and creates its own Received Signal Strength (RSS) finger print which is transmitted to the central station. However, compared with distance-estimation based techniques and RSS based techniques produce relatively small location estimation errors. Several area-based localization algorithms were proposed by Elnahrawy *et al*. (2004). These algorithms are area based because instead of estimating the exact location of the non-anchor node they simply estimate a possible area. Ni *et al*. (2003), introduced weighted version of the RSS based localization technique which achieves a more accurate location estimate.

GPS receiver located on the earth derives its distance to a GPS satellite from the difference of the time a GPS signal is received at the receiver and the time the GPS signal is radiated by the GPS satellite. Capkun *et al*. (2001) explained the GPS disadvantages are expensive, cannot used by the indoors, confused by tall buildings or other environmental obstacles.

Hussain and Trigoni (2010) proposed the use of ’localizers’ for enabling better localization accuracy in the presence of clutter between the references and un-localized nodes. Localizers help these nodes to localize more accurately than they would in case of single-hop localization which will involve distance measurements with large NLOS (Non-Line-of-Sight) errors. Drake and Dogancay (2004), proposed a solution for localization of distant transmitters based on triangulation of hyperbolic asymptotes. Hyperbolic curves are approximated by linear asymptotes. Distance vector-Hop localization technique introduced by Ibrahim *et al*. (2013).

Describes the anchor node broadcast their actual positions to the Sensor Node. Sensor Node keeps the shortest number of hops to each anchor node along with the anchor node’s position. Sensor Node saves the average single hop from the closest anchor node and forwards it to its neighbors. Conversely error in the DV-Hop localization technique appears since it assumes all hops to have the same value. Tang and He (2013) proposed Cramer-Rao Bound analysis (CRB) analysis can be applied to both centralized and distributed localization algorithms to determine the unknown nodes’ locations. In the CL-refine algorithm, local refinement is used, that is the locally available distances between any two neighboring nodes are also reported to the sink for location estimation. Sau *et al.* (2005) proposed Density-aware Phase is to enable individual nodes to share hop-count information collaboratively in order to determine their distances from individual reference nodes. The hop-count information incorporates density information so that it provides more accurate distance estimation. The Path-Length aware Phase, a node determines the confidence level for each estimated distance and decides if the distance should be used in position computation using triangulation. Density aware phase is use to node’s local density information to address density issue. The Path length assigns confidence level to address path length issue.

The utility of Nonparametric Belief Propagation (NBP), a recent generalization of particle filtering was demonstrated by (Ihler *et al*., 2005), for both estimating sensor locations and representing location uncertainties. NBP has the advantage that it is easily implemented in a distributed fashion, admits a wide variety of statistical models and can represent multimodal uncertainty. Robust distributed localization of sensor networks with certain distance measurement errors criteria was explained by Moore *et al*. (2004). Robust distributed localization is selection of the sub graphs of the representative graph of a network to be used in a localization algorithm robust against such errors. However, is not complete and there may be other criteria that may better characterize robustness of a given sub-network against distance measurement errors.

Savvides *et al*. (2005), proposed Cramer-Rao bound and simulations to investigate the error characteristics for a specific scenario in which anchors are located near the boundary of the region and non-anchor nodes are located inside the region. Several qualitative trends on how localization error varies with average node degree, number of anchors and distance to anchors are observed. This hypothesis needs to be validated with the estimators used in various localization algorithms and the class of algorithms which minimize the sum of the square of the difference between measured distances and estimated distances. Most of the works previously achieved and validated for node localization remain as motivation for the design of MCL technique, whereas RSS, GPS and triangulation serve as parts of the proposed strategy.

PROPOSED METHODOLOGY

In wireless underground sensor networks, the nodes need to update their location information at regular intervals to ensure the communication between the nodes in the network. Many protocols use distance between the nodes as one of the criteria for multi-hop communication in the network. There is the need to know the location of the nodes and the distance between the nodes in many power optimization protocols. But the question of how to obtain the distance or the location arises in the same.

Clearly, this protocol is a solution for determining the location of nodes to catalyze communication in the underground sensor networks. Initially there is a group of nodes deployed in the underground areas all of which connect to a sink that is further connected to the Base Station (Control Room). It is possible to locate all the nodes through GPS which can be used as a

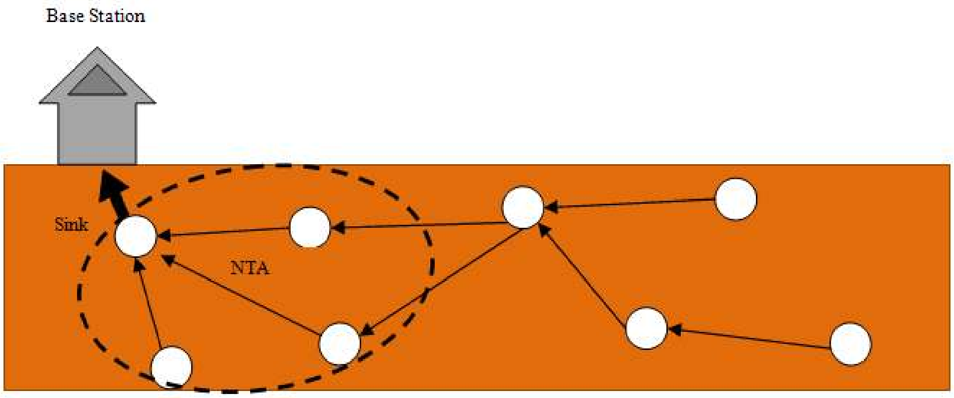

Fig. 2: Network topology in subterranean sensor networks

reference in the worst case scenario by the Base Station. The sink node has a Node Transmission Area (NTA) within which a node can be directly recognized by the sink node. In other words, direct communication is only possible with the nodes present within NTA as shown in the Fig. 2.

Each sensor node has a processor in which there is a separate memory that contains the co-ordinates of the sensor node which is updated and fine tuned after every communication process with its neighboring nodes. The MCL methodology used to achieve localization and hence communication is explained below.

The sink node S is capable of supplying the GPS information of every node $n \in V$ if required for reference purposes within the nodes randomly deployed that form the graph $G (V, E)$ with V vertices and E edges.

Step 1: Start
Step 2: The sink node S finds the nodes present within the NTA by broadcasting a pilot signal which is acknowledged by only the subset of nodes $S (V_{NTA}, E_{NTA})$
Step 3: The RSS values of the nodes within $S (V_{NTA}, E_{NTA})$ are measured to obtain the distances to the sink node S
Step 4: Sink node S uses the Cartesian co-ordinates of the nodes within $S (V_{NTA}, E_{NTA})$ to obtain the angle between line joining the sink S and the nodes (say A and B, as in Fig. 3)
Step 5: The sink now computes the distance between the adjacent nodes (d_{AB}) and transmits to the corresponding nodes
Step 6: The nodes within NTA update their tables with their distances to their neighboring nodes
Step 7: A node i from the NTA now becomes the arbitrary sink for the next set of neighbors from the subset $S (V_{NTAi}, E_{NTAi})$
Step 8: Go to Step 2 until all nodes know their distances and angles and have their neighbor tables updated
Step 9: Stop

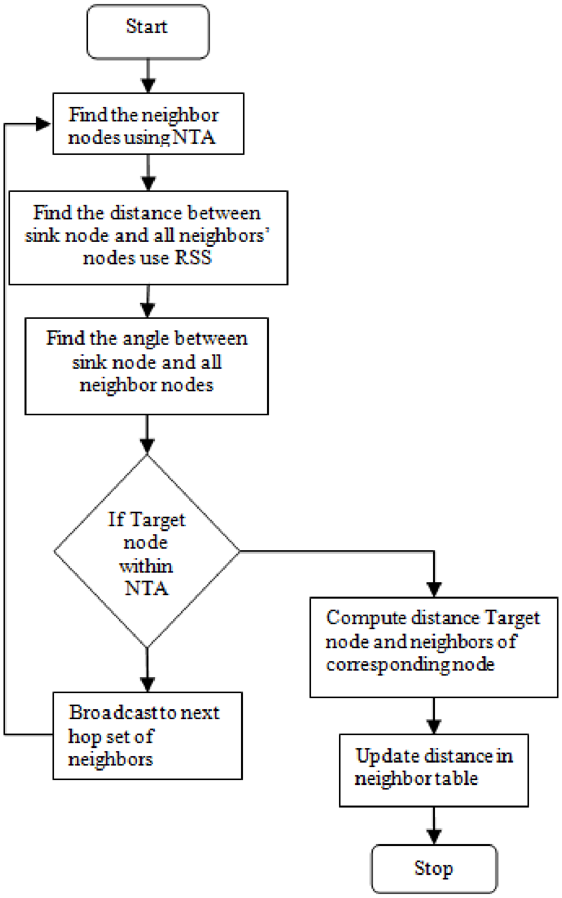

Fig. 3: Flow diagram of proposed system

Figure 4 shows that the nodes A and B belong to the subset $S (V_{NTA}, E_{NTA})$. According to the proposed strategy, the distances d_{SA} and d_{SB} are obtained from the RSS values of the acknowledgments received from A and B after the sink node sends a Pilot Signal using distance Eq. (1). The Cartesian co-ordinates of A and B are obtained from the GPS values stored by the sink are used to find the angles A makes with the line SB computed as $\angle BSA$ using Eq. (2):

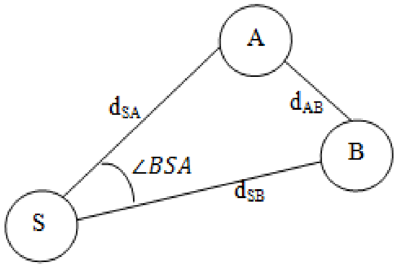

Fig. 4: Triangle formed by nodes

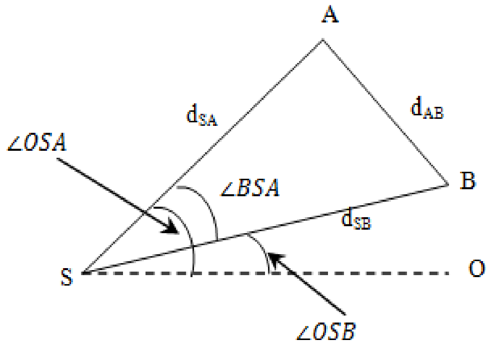

Fig. 5: Estimating angle from nodes

$$d = \sqrt{(x - x_1)^2 + (y - y_1)^2} \tag{1}$$

where x and x_1 are the co-ordinates of the two nodes between which distance d is estimated.

The two Cartesian co-ordinates of S and A are obtained using the GPS (4). This makes an angle ∠OSA with an arbitrary line SO. Similarly, ∠OSB is formed by obtaining the slope of the line SB formed by the individual co-ordinates of S and B. By obtaining these values the required angle ∠BSA is obtained as a difference between the two angles as in Eq. (4) (Fig. 5).

Angle between two lines joining S and A with corresponding co-ordinates x_s,y_s and x_a,y_a can be given by substituting Eq. (2) in (3):

$$\begin{aligned} dx &= x_s - x_a \\ dy &= y_s - y_a \end{aligned} \tag{2}$$

$$angle = \operatorname{Atan2}(dy, dx) \times \frac{180}{\pi} \tag{3}$$

$$\angle BSA = \angle OSA - \angle OSB \tag{4}$$

Having known the angle ∠BSA and the distances d_{SA} and d_{SB} it is possible to obtain the third side using the law of cosines, which is an extension of the Pythagoras theorem as in Eq. (5):

$$c^2 = a^2 + b^2 - 2ab\cos\theta \tag{5}$$

Hence according to our system model, the Eq. (5) can be rewritten as:

$$d_{AB}{}^2 = d_{SA}{}^2 + d_{SB}{}^2 - 2d_{SA}d_{SB}\cos\angle BSA \tag{6}$$

Thus the distances of all the nodes in the network can be estimated and their co-ordinates updated when this process continues for all nodes.

Data transmission: The above mentioned process is consecutively progressed from the Sink Node's NTA until all other nodes in the network are discovered and located. For every communication process, a node in the current NTA becomes the sink for the next set of nodes.

The known position of the target T is obtained from the sink through the GPS co-ordinates. As shown in the Fig. 6, the shortest route to the target nodes from

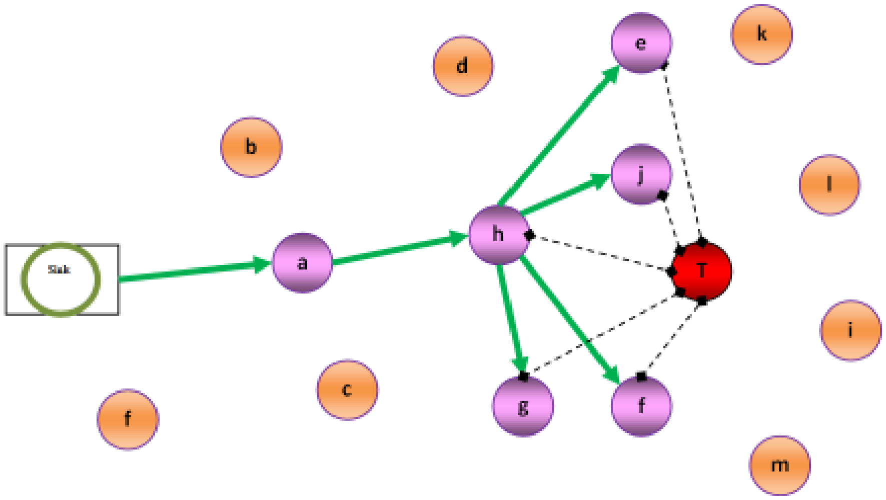

Fig. 6: Localization of a target

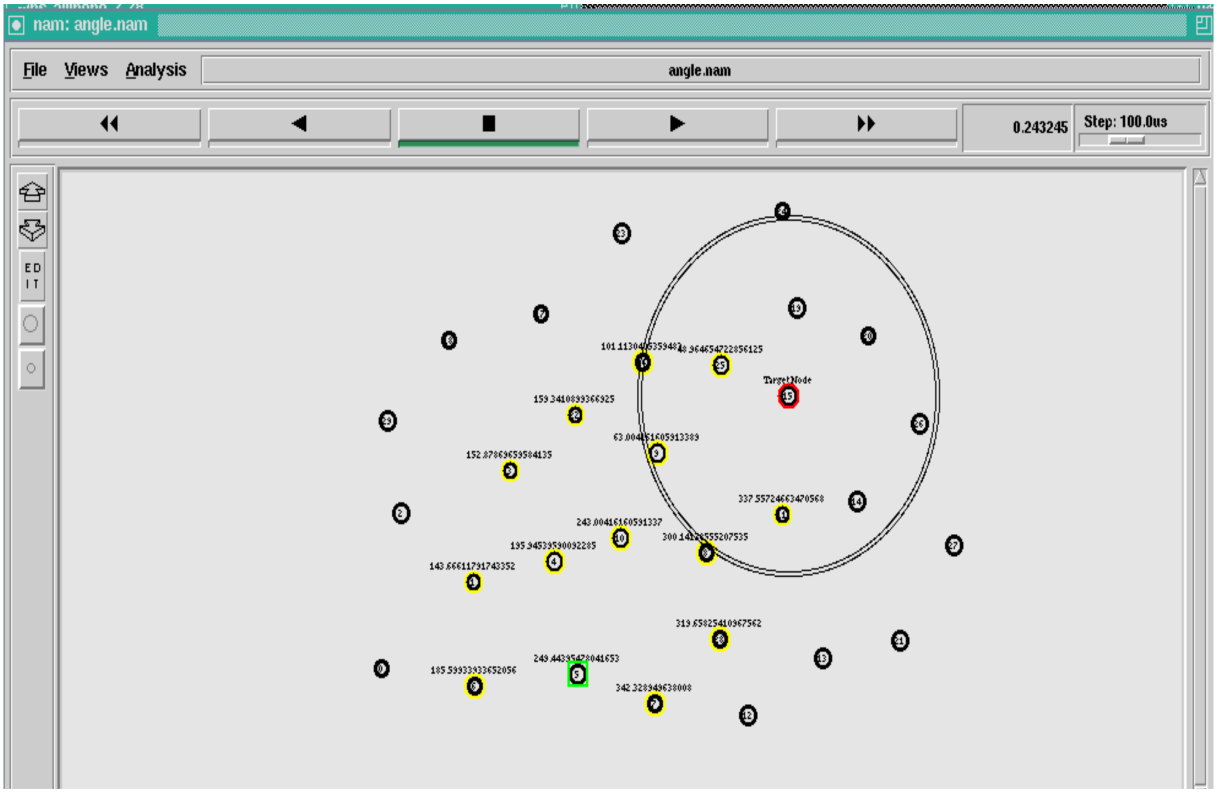

Fig. 7: Simulation experiment scenario of MCL

the sink is Sink-a-h-T, which means *h* is the last intermediate hop before the target in the route. The nodes in the neighbor list of this intermediate node *h* find the distances to the target node. To achieve this, only once the GPS co-ordinates of T are used to measure the distance d_{HT} and this is used along with d_{HG} and the angle ∠GHT to find the distance of target *T* from the node *g* (d_{GT}).

Similarly, all nodes that can sense the signals from T estimate their distances to the target T and report to the base station using which the target can be ultimately localized. In other words, this technique is an attempt to use RSS and triangulation hop by hop to both localize and communicate to the subterranean sensor nodes present in the network.

Table 1: Simulation parameters

Parameter	Value
Number of nodes	30
Routing protocol	DSDV
Traffic model	CBR
Simulation area	1500×700
Transmission range	250 m
Antenna type	Omni antenna
Mobility model	Two ray ground
Network interface type	Wireless Phy
Channel type	Wireless channel

RESULT ANALYSIS

To validate the method proposed here, a simulation scenario with 30 nodes deployed and configured as the subterranean wireless network is used with the specifications mentioned in the Table 1. Programming in C++ and Object-oriented Tool Command Language (OTCL) is done to determine the locations of various targeted nodes.

Since this is a unique approach, simulations are performed analyze both communication efficiency and accuracy of localization. A number of experiments were conducted to find a target and then obtain the data sensed by the target node functioning together as a network. At every execution, various target nodes are entered to find distances between the nodes around it using the MCL technique proposed here. The difference in the distances is a metric to know the efficiency of the localization.

Figure 7 represents the scenario considered for the simulation performed. Experimental results of the simulation model with the above specifications are shown in the Table 2. Here, the distances to the neighboring nodes from the target are measured both computationally and directly using the distance formula.

Table 2 shows that there is minimal variation in the distances obtained computationally and actually. The differences in the distances obtained are plotted in the given Fig. 8, which shows the efficiency of this method. On a minimum there is 0.161 m difference in distance estimated by the computational method from the actual distances from the target to their neighbouring node.

Table 2: Computational distance and actual distances from the target

Target node	Neighbour node	Computational distance (m)	Actual distance (m)	Difference in distances (m)
6	4	195.23383540	194.80503070	0.42880460
6	1	129.31556540	129.01550290	0.30006250
15	8	228.64911430	229.17242410	0.52330980
15	9	206.40328940	206.24257560	0.16071380
15	11	145.14021670	146.34206500	1.20184834
15	16	220.42703340	220.04544990	0.38158360
15	19	108.88394670	108.77959370	0.10435310
15	25	107.22951910	106.97663300	0.25288610
25	9	143.50174330	143.17821060	0.32353260
25	22	224.96288830	224.72205050	0.24083780
25	23	96.33319893	96.13012015	0.20307880
29	4	226.00952550	225.85836270	0.15116280
29	1	201.78476270	201.43485300	0.34990970
29	17	181.40848620	181.10770270	0.30078340
29	18	98.80436726	98.73196038	0.07240690
29	22	174.42360820	174.10341750	0.32019070
29	2	140.69047050	140.42791750	0.26255300
5	6	154.07563760	153.73335360	0.34228410
5	10	178.39504050	179.42407870	1.02903819
5	1	192.80269610	192.4084198	0.39427630
5	24	113.98798380	113.7013632	0.28662060

Table 3: Comparison of actual distance, MCL, DV HOP

Reference	Target	Actual distance	MCL	DV HOP	Difference between A.D and MCL	Difference between MCL and DV HOP
0	26	851.718	851.633	850.952	0.085	0.681
2	29	140.427	140.413	140.301	0.014	0.112
1	28	370.669	370.632	370.336	0.037	0.296
2	19	636.968	636.777	636.013	0.191	0.764
22	7	375.046	374.934	374.484	0.112	0.450

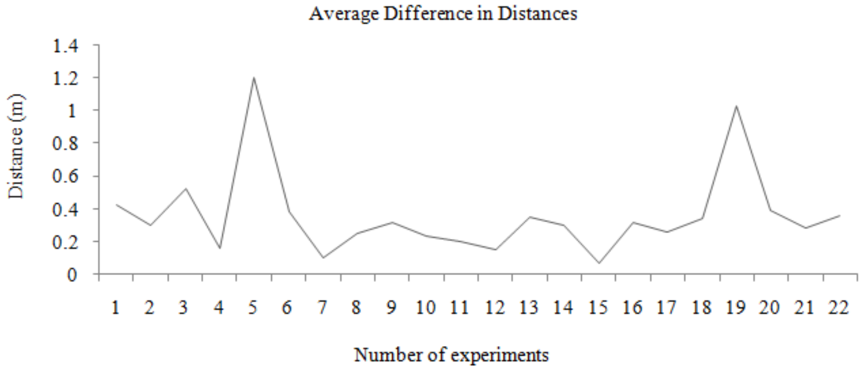

Fig. 8: Average distance variations

The maximum difference in distance is 1.029 m which leaves an average difference in distances as 0.363.

Table 3 shows the comparisons of actual distance, MCL, DV hop and difference between actual distance and MCL also compare the difference between MCL and DV hop techniques.

Throughput of the messages MCL is measured to ensure that the normal working of the sensor network is not interrupted by the working of the localization method proposed here. Throughput is the total number of packets successfully received at the receivers over the simulation period. Figure 9 shows that there is good throughput across the network.

If the target node is present in NTA, the sink sends the data directly otherwise the sink sends the data through multiple hops. Figure 10 show that when the hop counts increase, the distance will also increase. This figure shows MCL takes less time to transmit data than existing DV Hop.

Figure 11 shows the graph between distance and time. If the target node exist NTA, the target node receives the data instantly. Otherwise the sink sends the data through multiple intermediate nodes until it reach the target node. So the time increase or decrease based on the distance.

Figure 12, it is clear that the delay in transmission time for the proposed system (MCL) is extremely low compared to that of the existing system (DV HOP). The Delay is calculated by the formula (7) given below:

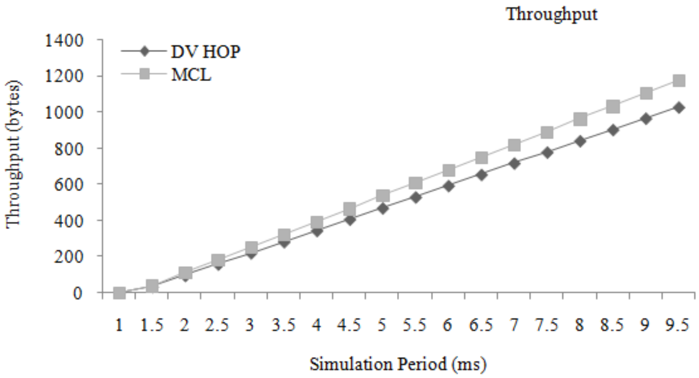

Fig. 9: Throughput

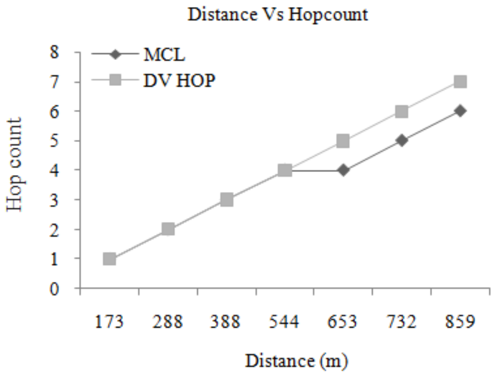

Fig. 10: Distance vs. hop count

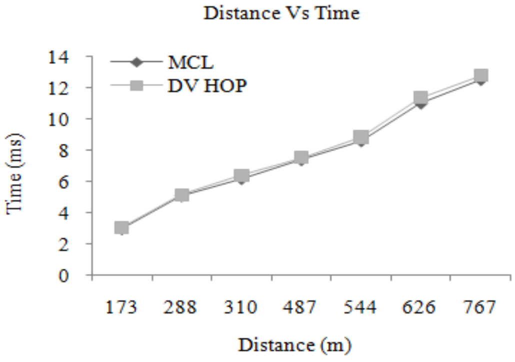

Fig. 11: Distance vs. time

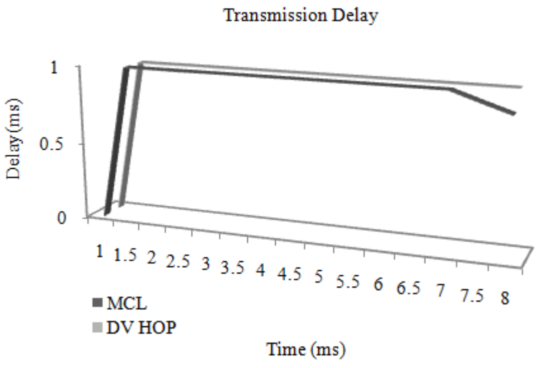

Fig. 12: Transmission delay

$$Transmission\_delay = \frac{LastPacketTime}{CurrentTime} \tag{7}$$

CONCLUSION

It can be observed from MCL method that the target localization can be achieved by using the angles and the distance method to achieve good accuracy in identifying the node transmission. Improvement of network throughput has been analyzed with different algorithms. Our method can be extended for further applications of underground networks. The MCL method can hence help in localization of a target node, communication of sensed information back to the base station with higher throughput by taking less time. MCL takes lesser time in to transmitting data delay in processing the data, transmission will be slow, when compared in with DV-hop technique. In this case, it can be concluded that MCL outperforms DV-hop in time and distance measurement for locating the target node. A combination of MCL with the other localization techniques like DV-hop and DV-distance is proposed as part of future works.

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