The Journal of The Institute of Internet, Broadcasting and Communication (IIBC)
Vol. 18, No. 5, pp.77-87, Oct. 31, 2018. pISSN 2289-0238, eISSN 2289-0246

https://doi.org/10.7236/JIIBC.2018.18.5.77
JIIBC 2018-5-10

무선 센서 네트워크의 고정 위치에 대한 정확도 향상

An Accuracy Enhancement for Anchor Free Location in Wireless Sensor Network

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요 약 WSN에 국한하여 많은 연구가 이루어졌다. 정적 WSN에 국한된 솔루션은 모바일 WSN에 적용하기가 어렵다. 모바일 WSN에 국한된 솔루션은 네트워크에 상당한 수의 앵커 노드가 있다고 가정하고 리소스가 제한된 상황에서 이러한 솔루션은 정적 및 모바일 혼합 WSN에 적용하기가 어렵다. 앵커 노드를 사용하지 않고 정적 노드와 모바일 노드가 혼합 된 혼합형 무선 센서 네트워크에 대해 효율적이고 정확하며 신뢰할 수 있는 방법으로 국한하여 서비스를 제공 할 수 없다. 정확도는 혼합 무선 센서 네트워크에 한정하여 중요한 요소이다. 본 논문에서는 무선 센서 네트워크에서 앵커 노드가 없는 위치 파악의 정확성에 대한 요구를 만족시키는 방법을 제시하였다. 홉 좌표 측정은 앵커 프리 로컬화를 위한 정확한 방법이 사용됩니다. 동일한 범주의 동일한 데이터를 사용하는 다른 방법과 비교할 때 이 방법은 다른 방법보다 정확도가 좋다. 또한, 우리는 WSN에서 앵커 노드가 없는 지역적으로 낮은 통신 및 계산 비용과 같은 효율성에 대한 요구를 충족시키기 위해 최소 스패닝 트리 알고리즘을 적용했다. Java 시뮬레이션 결과는 제안된 접근 방식을 질적인 방법으로 수정하고 다양한 게재 위치에서 실적을 이해하는데 도움이 된다.

Abstract Many researches have been focused on localization in WSNs. However, the solutions for localization in static WSN are hard to apply to the mobile WSN. The solutions for mobile WSN localization have the assumption that there are a significant number of anchor nodes in the networks. In the resource limited situation, these solutions are difficult in applying to the static and mobile mixed WSN. Without using the anchor nodes, a localization service cannot be provided in efficient, accurate and reliable way for mixed wireless sensor networks which have a combination of static nodes and mobile nodes. Also, accuracy is an important consideration for localization in the mixed wireless sensor networks. In this paper, we presented a method to satisfy the requests for the accuracy of the localization without anchor nodes in the wireless sensor networks. Hop coordinates measurements are used as an accurate method for anchor free localization. Compared to the other methods with the same data in the same category, this technique has better accuracy than other methods. Also, we applied a minimum spanning tree algorithm to satisfy the requests for the efficiency such as low communication and computational cost of the localization without anchor nodes in WSNs. The Java simulation results show the correction of the suggested approach in a qualitative way and help to understand the performance in different placements.

Key Words : Wireless sensor network, Anchor free location, Minimum spanning tree, Java simulator

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게재확정일자 : 2018년 10월 5일
Received: 19 August, 2018 / Revised: 19 September, 2018 / Accepted: 5 October, 2018
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Ⅰ. Introduction

Wireless sensor network (WSN) has many applications such as target or vehicle tracking, thing detection or monitoring and routing etc. In all of these applications, measurement data are not usable without knowing about the location of the sensor nodes. Location scheme is an important problem in the WSNs. Location scheme has the process of estimating and optimizing the positions of sensor nodes[1]. The simple way is manual deployment but it is impractical in case that the sensors are large scale or deployed in inaccessible areas or used mobile sensors. As another way, global positioning system can be applied to each sensor. The global positioning system has affected by special environment because it needs line-of-sight between the receiver and satellites. Therefore, it has low accuracy because of signal reception errors. Also, to use the global positioning system in large scale is very expensive. Thus, many localization schemes have been discussed to solve this problem. Several applications introduce not only location awareness of WSN nodes but the relative locations of WSN nodes[14]. Also, there are some different geographic routing methods which are specifically designed to satisfy different applications of WSNs[15]. All of them use the relative locations of sensor nodes such as selecting neighbors with the shortest projected distance. A basic concept needed to use and maintain the WSNs is localization that is defined to be the determination of the real position of each sensor node in a geographic map, or searching its relative location according to the topology type. Location problem involves both static nodes and mobile nodes in WSNs. Even though pure mobile networks are used like in vehicle WSNs, some vehicles can park somewhere for a short time. So they can be regarded as static nodes at that time [17]. However, the localization schemes of the static WSN cannot be applied to the mixed WSN case without a significant increase in communication and computational costs. Some works regarding to the localization of mobile WSN use the assumption that there are many number of anchor nodes in the networks. These approaches are not desirable in communication and computational cost, and have some weak points for resource limited WSN. Without the use of anchor nodes, none of the suggested systems can use and maintain the WSNs in efficient and reliable ways. In the anchor based localization scheme, many nodes are usually required to obtain their locations having some desirable estimation errors[16]. The reasons of the inaccuracy at current measurement techniques are mainly hop counting and connectivity Technique. In order to obtain the hop count, a previous appointed bootstrap node is needed, which sends out a hop counting message. Every other node determines its hop distance from the bootstrap node by using this hop count message and sends the message after accumulating the hop counts. It is an efficient way to measure the distance between any two arbitrary nodes in WSNs. Connectivity information is used to measure the distances between pairs of nodes inside of the network. Similar to the hop count, many nodes share the same measured distance in the connected scheme even though they do not have the same physical distance to other nodes. There is more information hidden in the neighbors of a node. The hop coordinates approach is desirable to collect and use this neighbor information[18]. Hop count and connectivity techniques do not utilize this neighbor information. In this paper, we apply the hop coordinate approximation for anchor free location to improve the accuracy of measurement as well as localization. Also, efficiency is another consideration in our approach under resource limited WSNs. Applying minimum spanning tree algorithm can be reduced the communication and computational cost. A tradeoff between accuracy and efficiency is an important issue in the mixed WSN localization. Our approach is implemented through Java simulator that is designed for an anchor-free localization of nodes in WSN defined by IEEE 802.15.4 standard.

Ⅱ. Localization process

WSNs are consisted of many sensor nodes, each of which has sensing devices, a processor, and a battery. The sensor nodes are typically communicated via radio frequency signals. A localization process is to estimate the position of each sensor node in a WSN. Most inputs of the localization process become the location of anchors in case that there is any anchor available in WSNs. Other inputs are connectivity information for range free manners, distance or angle between nodes for range based manners using signal modality. For the anchor based schemes, the output of localization process is absolute coordinate while the anchor free scheme is usually relative coordinate. Fig 1. denotes each step in WSN localization process.

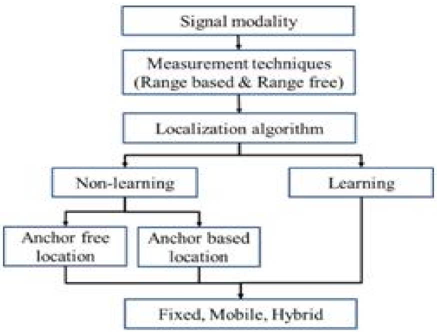

그림 1. WSN 기반 절차
Fig. 1. WSN localization process

Signal modality has high effect on the accuracy of location estimation. A sufficient signal type selection depends on the various factors such as node hardware, the application and environment. Using additional hardware is not proper in terms of cost and energy. Different environment has various effects on the performance of location determination. For example, acoustic performs better than radio signal in humidity effect because moisture absorbs and reflects high frequency radio. Further, different applications make different constrains to choose a signal type. For instance, in military environment, the sensor nodes should be deployed in the silent manner. Acoustics are also used in many localization schemes like Ultra in cricket approach and audible in beam forming[2][3]. Infrared signal cannot be used for outdoors because of high attenuation and its difficulty to read in case that sunlight is available. All sensors have onboard radio hardware. Frequency, phase and strength of the frequency radio are used for the localization process. Light can be used for some approaches like spotlight method[4]. But, line of sight, powerful light source and special hardware are required. Each sensor node in the network sends a signal. This signal will be processed on the receiver nodes in order to measure the ranges or in order to count the hops. Conventional techniques are divided in two categories. Range estimation methods compute the distance or angle between two neighbor nodes. The usual methods of this category are Time-Of-Arrival, Time Difference of Arrival[5], Angle of Arrival[6], or the Received Signal Strength Indication[7]. They use the phase or time difference to obtain the measurement. Other hardware requirements such as cost, complexity, noise sensitivity and additional energy consumption are needed for these methods. Even though range free schemes can be used to be independent of hardware and ranging error, the cost is expensive. They use only connectivity information and hop counts between nodes to estimate the node position. These methods are adequate to many applications.

The output of localization process is in form of absolute or relative location. Most of the anchor based categories use absolute coordinate output. The absolute location is defined by position-specific nodes. In some cases, the absolute locations obtain from relative locations by using linear transmission and some references. The absolute result is easy to use. Mostly, the outputs of anchor free schemes are relative coordinates. Relative position is the relationship of distance and angle between the network nodes. It is more proper for some applications. The relative coordinate of nodes is defined by manual configuration or references. It can also transform to the absolute localization. Based on the inputs data, a localization scheme estimates the location of nodes in the network area. Inputs can be range estimation with or without the location of beacons or access points. Available schemes are divided into learning based method and without learning based method[13]. Generally, machine learning based localization schemes are composed of offline training phase and online Most of the localization schemes use without learning methods, and are classified into anchor based and anchor free methods. Anchor represents the nodes which are aware of their positions because of adding GPS or manual configuration. In the anchor based methods, the location accuracy depends on the number of anchors and their distribution in the network. The anchor based methods can be deployed in the fixed, mobile or mixed networks. Fixed networks contain of static sensor nodes and they are used to localize non-aware nodes. The mixed networks are consisted of static nodes and mobile beacon which is served as a static node for representing its accurate position. The purpose of mixed networks is to localize static nodes. Though the mobile networks make the wireless sensor networks more flexible and give more possible applications, they represent few problems such as latency and Doppler shift that happens when transmitter moves relative to the receiver. The without learning schemes can be implemented in centralized, locally centralized and distributed manner. In the centralized manner, the entire network information is sent to a central unit to analysis, and then computed positions are transported back into the network. Since sending all data to the unit sink causes bottle neck problem, it is more suitable for small scale area networks. Convex position method is a centralized localization algorithm for fixed networks, which is based on some computations with high cost[8]. Since it is executed by a single centralized node, it is not suitable for many ad hoc environments. The locally centralized implementation uses two or three central units. It can be used to overcome high communication overhead and scalability limitations of the centralized manner. CBLALS is a locally centralized localization scheme for the static networks, which uses ultrasound and frequency radio signals with TDOA measurement technique to localize indoor sensors[10]. In the distributed manner, all the relevant computation is done on the sensor nodes themselves. Therefore, it is difficult to implement, but there are computational efficient and more flexible for large scale networks. Distributed grid-based transmitting power is a distributed localization algorithm, in which anchor nodes can change their communication range by increasing their transmitting power[9]. Each node establishes a rectangular coordinate system and divides it into square grids. In contrast to anchor based schemes, non-learning anchor free localization algorithms has not even one anchor node. In these schemes instead of finding the nodes' position, the algorithm finds relative positions of the nodes in the coordinate system by a reference group of nodes (anchors). These approaches can be deployed in fixed, hybrid and mobile networks with the same properties as mentioned in the last section. There is also many localization techniques implemented based on Centralized, Locally Centralized and Distributed. The methods which are in[11][12] involve in the category of anchor free and without learning localization schemes. Basically, the multi-dimensional scaling technique uses data analysis and information visualization to display distance-like data in geometrical visualization. This algorithm computes the shortest distance between all pairs of nodes and then generates a distance matrix and applies the multi-dimensional scaling to obtain the relative location of nodes. If there was sufficient anchor numbers available, it can estimate the position of absolute nodes by transforming relative positions. It requires global information and it has high communication and computation cost.

Ⅲ. Improving measurement accuracy

In this section, we present an approximation scheme to use on any localization algorithms to which hop counts or connectivity information can apply. The basic concept of hop counts is that there is a special bootstrap node in the network, which sends out a message to flood the network, and all other nodes in the network will use this message to count the number of hops to that bootstrap node. It is an efficient way to measure the distance between any two arbitrary nodes in WSNs. However, the problem is that this method only distinguishes nodes based on the number of hops between them, so if many nodes share the same number of hops distance from the bootstrap node, they cannot be differentiated. A unit disk graph is typically used to represent connectivity information. Connectivity technique uses the information to represent the topology of a network. Connectivity information is used to measure the distances between pairs of nodes inside of the network. Both hop counts and connectivity techniques use connectivity information to measure the distance inside a network. Similar to the hop counts, the connectivity based technique also has the problem that many nodes share the same measured distance even if they do not have the same physical distance to other nodes.

1. Some localization approximation techniques

Since hop counts and connectivity schemes are not so accurate for measurement, some approximations to improve the accuracy of measurements have been suggested. The average number of adjacent nodes plays an important role in computing the distance based on the connectivity [20]. Nagpal et al. suggested an approximation technique based on KS expressions[19]. It is a relation between the hop approximation a_h and the number of neighbor n as the following:

$$1+\exp(-n)-a_h=\int_{-1}^{1}\exp\left(-n\left(\cos^{-1}(t)-t\sqrt{1-t^2}\right)/\pi\right)dt \tag{1}$$

Using this hop approximation, it is easy to compute the distance from some source node to special node. But, this approximation considers only the density of a wireless sensor network. The approximation does not consider the number of hops that a measurement message has traveled to reach the target node. Pascal et al. evaluated the physical mean distance from a given sensor node to each of its neighbors using the number of hops and the number of neighbors[21]. This approximation is to use not only the number of neighboring nodes, but also the number of hops that have been traversed. For each value of the number of neighboring nodes, varied from one to thirty, they generated twenty networks of 5000 sensors. In each network, they computed the hop distances from each sensor to every other one. Using values of the hop distance and the number of neighboring nodes, they finally evaluated the average distance. Compared to KS approximation, this approximation shows the relation between the hop approximation and the number of hops traversed. But, it still loses much information to improve the accuracy of the measurement, since it does not consider the difference between the locations of their neighboring nodes. For example, if the neighboring nodes of one node change their locations slightly, but do not leave that node's neighborhood, this approximation will not discover such a movement. Hop coordinates approximation tries to collect and utilize more information hidden in the neighbors of a node[18]. It not only counts the number of hops from some bootstrap node, but also offsets it with the local network information of that node. A hop coordinate technique is composed of two parts: number of hops in a minimum hop route from some bootstrap node to a given node and offset. The offset can be seen as a decimal fraction generated from local network information. This technique improves the accuracy of the measurement when compared to the other techniques. However, it does not outperform most other algorithms in case of anchor-free location, and the computation cost is expensive since it includes the optional refining steps. Anchor-Free localization does not need to rely on anchor nodes neither at the time it is measures the distance between nodes, nor at the time when it computes the node coordinates.

2. minimum spanning tree application and transformation

A wireless sensor network can be regarded as a connected undirected graph. A breadth-first algorithm and a backtracking greedy algorithm transform the path planning issue into seeking spanning trees of the undirected graph and traversing through the graph. Thus, the movement trajectory of the mobile anchor node changes dynamically accordingly to the distribution of unknown nodes. Let h_t be the minimum number of hops to reach node t counting from some bootstrap node, N_t a node set that can be reached by node t in a single hop, and $|N_t|$ the number of nodes in N_t. Then, the number of offset for a hop coordinates can be computed as the following.

$$o_t = \{\sum_{i \in N_t}(h_i - h_t + 1) + 1\} / \{2(|N_t| + 1)\}, |N_t| \neq 0 \quad (2)$$

If N_t is empty set, then o_t = 0 and h_t > 0. In case that node i is an arbitrary node in N_t, the hop distance between node t and i is at most 1 hop, $|h_t - h_i|$ £ 1. After hop coordinates is computed, the distance between two nodes can be estimated by multiplying the radio range for a node in the network. Our approximation scheme can be summarized in three steps. First step is two bootstrap nodes selection with longest distance and computing hop coordinates for these bootstrap nodes. Suppose that b bootstrap node candidates from total n nodes in the network are assigned, and that these candidates are randomly mixed into the total n nodes. Every candidate floods a message out to count the hop distance from itself to other candidate. Each candidate has a b´1 pair-distance vector for the b candidates, and each candidate broadcasts this vector to other candidates. In case that there are several pair candidates with the same longest distance, then we resolve ties by selecting the pair of candidates in order of their identification number. For the selected bootstrap nodes X and Y, initialize with one message from each with variables h_X and h_Y to flood the network. Every other node records its number of hops from two bootstrap nodes, and computes the integer part of its hop coordinate. Second step is to generate local center nodes. In this step, the network first separates the whole network area into several local areas based on hop coordinates generated in the first step, and then select a local center node for each local area. In order to select a center node for each local area, we apply simple voting method that selects a node as near as possible to the ideal center position. We use the distance from this node to the center position as the parameter for a delay weight. After at least one center node for each local area is generated, each center node sends a request to its neighbor nodes that are within hops to send back their hop coordinate from the bootstrap node. Third step is to apply a minimum spanning tree algorithm to calculate the local map in each center node. After the center nodes for each local area are generated, each center node has a pair distance matrix for all nodes in the local area. Minimum spanning tree algorithm can be applied to the distance matrix to generate a local map for each center node. Since each center node has a local map for its local area with its own coordinates system, there are many local maps with their own coordinates in the network. To merge all local maps into a global map, a transformation matrix must be evaluated for each local map to transform the local map into the global map. Start with local map of the center node assigned randomly, and then select a neighbor center node that its local map shares the most nodes. This procedure is continued until there is no center node. The set of neighboring center node is found for each center node.

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Ⅳ. Simulation Results

A Java simulator is used to an anchor-free localization of nodes in wireless sensor network defined by IEEE 802.15.4 standard. The simulator can designate a number of sensor nodes, a measurement error, a topology of network and type of distance measurement technique. The trend of energy consumption in a dependency on a number of optimization steps is the output of the simulator. The final located layout is also the output of the simulation. The simulator implements the suggested to satisfy the requests for the accuracy of the localization without anchor nodes in the wireless sensor networks. Hop coordinates measurements are used as an accurate method for anchor free localization. Also, we apply a minimum spanning tree algorithm to satisfy the requests for the efficiency such as low communication and computational cost of the localization without anchor nodes in the wireless sensor networks. Sensor types used in this simulator are summarized in Table 1. Microchip, Nordic Semiconductor, and Texas Instruments utilize on-chip buffers for the adaptation of a high-speed radio with a low-speed MCU. Current consumptions are specified at the lowest band and 0 dBm transmission powers. The table indicates that data rate and frequency band has only a low effect on current consumption. The last two columns denote the energy consumption of a received and transmitted bit of data, which are determined using 3.0V supply voltage. The comparison indicates that radios operating at the 2.4 GHz frequency band are the most energy-efficient, which is mostly caused by their high data rates.

표 1. 무선 기능, 전류 소비, 에너지 효율성
Table 1. Radio features, current consumptions, and energy efficiencies.

Radio features	Data rate (kbps)	Band (MHz)	Buffer (B)	Sleep (µA)	RX (mA)	TX (mA)	RX (nJ/b)	TX (nJ/b)
MC	*250*	2400	128	2	18	22	264	216
MRF24J40	*1000*	2400	32	0.9	19	13	39	57
NS nRF2401A	*2000*	2400	32	0.9	12.3	11.3	17	18
NS nRF24L01	*50*	433-91	32	2.5	14	12.5	750	840
NS nRF905	*1000*	5	32	1.5	24	19	57	72
TI CC2400	*250*	2400	128	1	18.8	17.4	209	226
TI CC2420	*500*	2400	64	0.4	17	21.2	127	102
TI CC2500	*500*	2400	64	0.4	16.5	15.5	93	99
TI CC1100		433-915						

Abbreviations: Microchip (MC), Nordic Semiconductor (NS), Texas Instruments (TI)

The designed simulator can select random and grid types as a network topology, and display its layout into GUI window. Also, 100, 200, 300 or 400 nodes and degree of node 4, 8 or 12 are selected. Using node degree, nodes estimate a location based on the concept that the estimated location should optimize the possibility of the observation. A simple concrete example of a deployment model is a uniform random placement of nodes over a given area. Fig 2. shows a created random topology in case of using MRF24J40 as the sensor type. Here, we used 100 nodes and 4 node degree. Fig 3. shows a location optimization result by using typical anchor free location. Before the estimation and optimization, the energy consumptions are summarized as: 11.2 mJ (max), 7.76 mJ (average) and 3.2 mJ (min). Afore the estimation and optimization, the energy consumptions are summarized as: 12.43 mJ (max), 9.12 mJ (average) and 3.65 mJ (min). Before the optimization, the messages sent by sensor are summarized as: 21 (max), 15 (average) and 13 (min). Also, the messages received by sensor are summarized as: 124 (max), 75 (average) and 13 (min). After the optimization, the messages sent by sensor are 23 (max), 18 (average) and 14 (min). Also, the messages received by sensor are 137 (max), 88 (average) and 17 (min).

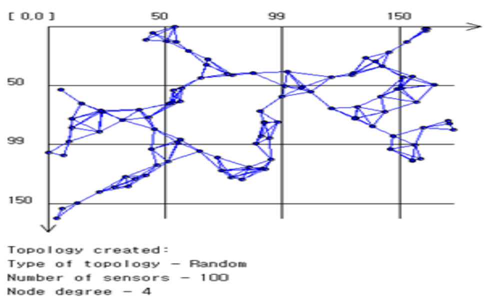

그림 2. A 랜덤으로 생성된 토폴로지
Fig. 2. A created random topology

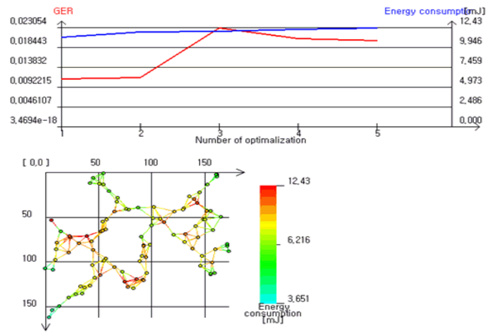

그림 3. 위치가 없는 전형적인 앵커의 근사 결과
Fig. 3. Approximation result by typical anchor free location

Fig 4. shows a location approximation result by using the suggested anchor free location. The energy consumptions before approximation are summarized as: 10.66 mJ (max), 7.62 mJ (average) and 3.2 mJ (min). The energy consumptions after approximation are summarized as: 12.32 mJ (max), 8.83 mJ (average) and 3.45 mJ (min). Before the approximation, the messages sent by sensor are summarized as: 21 (max), 15 (average) and 13 (min). Also, the messages received by sensor are summarized as: 124 (max), 74 (average) and 13 (min). After the approximation, the messages sent by sensor are 23 (max), 17 (average) and 14 (min). Also, the messages received by sensor are 146 (max), 86 (average) and 14 (min). Comparing with Fig 3. we can see that hop-coordinates outperforms hop-counting. Similar results are also obtained in case that the other sensor types are used.

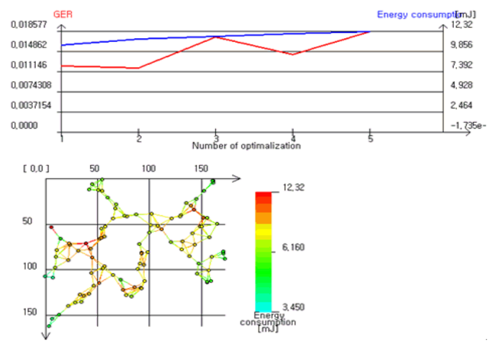

그림 4. 위치가 없는 제한된 앵커의 근사 결과
Fig. 4. Approximation result by suggested anchor free location

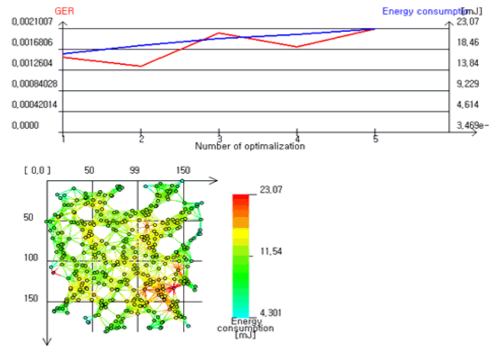

그림 5. 근사 결과(400 노드와 노드 차수 12)
Fig. 5. Approximation result (400 nodes and node degree 12)

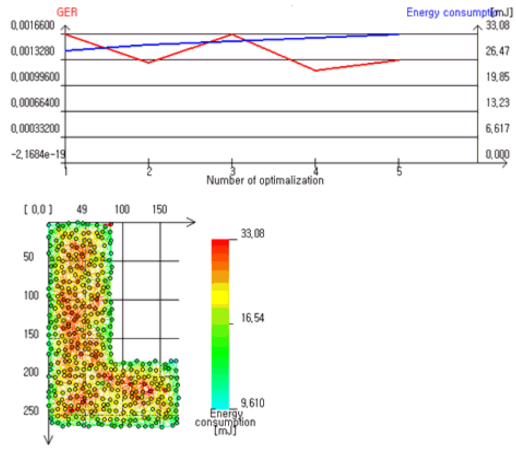

그림 6. 랜덤 L형 토폴로지에 의한 근사 결과
Fig. 6. Approximation result by random L-type topology

Fig 5. shows a location approximation in case of 400 nodes and 12 node degree. Hop-coordinates still outperforms other methods with respect to accuracy as well as the number of neighboring nodes. However, the uniform random placement of nodes may have undesirable side effects when applied to simulation studies, such as inaccurate estimates of node degrees in the topology connectivity graph, due to boundary effects at the edges of the simulated area (see Fig 6.). The hop coordinates as virtual boundaries are needed to improve the accuracy of localization. Then, the whole WSN must be divided into many local areas, and a node in each local area must be selected as a center node for that area.

Ⅴ. Conclusion

Currently, more context-specific applications have been developed in large scale wireless sensor networks. These applications are related to healthcare, surveillance, building monitoring and other applications. Localization is one of the fundamental elements for the context-specific application. Many researches have been focused on localization in static and mobile WSN. However, the solutions for localization in static WSN are hard to apply to the mixed WSN. The solutions for mobile WSN localization have the assumption that there are a significant number of anchor nodes in the networks. In the resource limited situation, these solutions are difficult in applying to the mixed WSN. Without using the anchor nodes, a localization service cannot be provided in efficient, accurate and reliable way for mixed wireless sensor networks which have a combination of static nodes and mobile nodes. Also, accuracy is an important consideration for localization in the mixed wireless sensor networks. In this paper, we presented a method to satisfy the requests for the accuracy of the localization without anchor nodes in the mixed wireless sensor networks. Hop coordinates measurements are used as an accurate method for anchor free localization. Compared to the other methods with the same data in the same category, this technique has better accuracy than other methods. Also, we applied a minimum spanning tree algorithm to satisfy the requests for the efficiency such as low communication and computational cost of the localization without anchor nodes in the mixed WSN. The simulation results presented here may not recur exactly in the real world applications. But these results verify the correction of the suggested approach in a qualitative way and help to understand the performance in different placements.

References

[1] Aspnes, J., T. Eren, D. K. Goldenberg, A. S. Morse, W. Whiteley, Y. R. Yang, B. D. Anderson, and P. N. Belhumeur. “A theory of network localization”, IEEE Transactions on Mobile Computing: pp.1663-1678, 2006
DOI: doi> 10.1109/TMC.2006.174

[2] Smith, A. and H. Balakrishnan, M. Goraczko, and N. Priyantha. “Tracking moving devices with the cricket location system”, Proceedings of the 2nd international conference on Mobile systems, applications, and services: pp. 190-202, 2004.
DOI: doi>10.1145/990064.990088

[3] Chen, J. C and K. Yao, and R.E. Hudson. Source localization and beamforming: Signal Processing Magazine, IEEE, (19): 30-39, 2002.

[4] Stoleru, R. and T. He, J.A. Stankovic, and D. Luebke. “A high-accuracy, low-cost localization system for wireless sensor networks”, Proceedings of the 3rd international conference on Embedded networked sensor systems: pp. 13-26, 2005.
DOI: doi>10.1145/1098918.1098921

[5] Tang, T. and Q. Guo, and B. Peng. “Sorted TDOA optimization based localization algorithm for wireless sensor network”, Computer Engineering and Applications, Vol.44, 25, 2009.

[6] Stefano, G.D. and A. Petricola. “A distributed AOA based localization algorithm for wireless sensor networks”, Journal of Computers, Vol. 3, No.4, April 2008.

[7] Zhuang, W. and G. Song, J. Tan, and A. Song. “Localization for hybrid sensor networks in unknown environments using received signal strength indicator“, Information and Automation, International Conference on, pp.567-572, 2008.
DOI: doi>10.1109/ICINFA.2008.4608064

[8] Doherty, L. and L. El Ghaoui. “Convex position estimation in wireless sensor networks”, INFOCOM 2001. Twentieth Annual Joint

Conference of the IEEE Computer and Communications Societies. Proceedings. IEEE: pp.1655-1663, 2002.
DOI: doi>10.1109/INFCOM.2001.916662

[9] Sun, C. and J.Xing, Y. Ren, Y. liu, J.Sha, J.Sun. "Distributed Grid-based Localization Algorithm for Mobile Wireless Sensor Networks", Advances in Electronic Engineering, Communication and Management Vol. 1, pp.315-321, 2012.
DOI: https://doi.org/10.1007/978-3-642-27287-5

[10] Shu, J. and R. Zhang, L. Liu, Z. Wu, and Z. Zhou. "Cluster-based Three-dimensional Localization Algorithm for Large Scale Wireless Sensor Networks", Journal of Computers, Vol.4, No.7, pp.585-592, JULY 2009.

[11] Pan, J.J. and J.T. Kwok, Q. Yang, and Y. Chen. "Multidimensional vector regression for accurate and low-cost location estimation in pervasive computing", IEEE Transactions on Knowledge and Data Engineering Vol.18, No. 9, pp.1181 - 1193, 2006.
DOI: doi>10.1109/TKDE.2006.145

[12] Youssef, A. and A. Agrawala, and M. Younis. Accurate anchor-free node localization in wireless sensor networks: Performance, Computing, and Communications Conference. IPCCC 2005. 24th IEEE International: pp.465 - 470, 2005.
DOI: doi>10.1109/PCCC.2005.1460614

[13] S. Afzal. A Review of Localization Techniques for Wireless Sensor Networks, J. Basic. Appl. Sci. Res., Vol.2, No.8, pp.7795-7801, 2012.

[14] J. Ortiz, C.R. Baker, D. Moon, R. Fonseca, and I Stoica. Beacon location service: A location service for point-to-point routing in wireless sensor networks. In Proceedings of the 6th International Conference on Information Processing in Sensor Networks (IPSN), pp.166-175, Cambridge, Massachusetts, USA, 2007.
DOI: doi>10.1109/IPSN.2007.4379676

[15] F. Kuhn, R. Wattenhofer, Y. Zhang, and A. Zollinger. "Geometric Ad-Hoc Routing: Of Theory and Practice". In Proceedings of the 21st Annual Symposium on Principles of Distributed Computing (PODC), pp. 63-72. ACM Press New York, NY, USA, 2003.
DOI: doi>10.1145/872035.872044

[16] A. Savvides, C.C. Han, and M.B. Strivastava. Dynamic Fine-Grained Localization in Ad-Hoc Networks of Sensors. In Proceedings of the 7th Annual International Conference on Mobile Computing and Networking (MobiCom), pp. 166-179. ACM Press, 2001.
DOI: doi>10.1145/381677.381693

[17] B. Hull, V. Bychkovsky, Y. Zhang, K. Chen, M. Goraczko, A. Miu, E. Shih, H. Balakrishnan, and S. Madden. "CarTel: a Distributed Mobile Sensor Computing System". In Proceedings of the 4th ACM Conference on Embedded Networked Sensor Systems (SenSys), pp. 125-138. ACM Press, 2006.
DOI: doi>10.1145/1182807.1182821

[18] Y. Xu. "Anchor-Free Localization in Mixed Wireless Sensor Network Systems", Dartmouth Computer Science Technical Report TR2008-626, May 2008.

[19] L. Kleinrock and J. Silvester. "Optimum Transmission Radio for Packet Radio Networks or Why Six is a Magic Number". In Proceedings of the IEEE National Telecommunications Conference, vol. 4, pp.1-4, 1978.

[20] R. Nagpal, H. Shrobe, and J. Bachrach. "Organizing a Global Coordinate System from Local Information on an Ad Hoc Sensor Network". In Proceedings of 2nd International Works hop of Information Processing in Sensor Networks (IPSN), Palo Alto, CA, USA, pp.333-348, April 2003.
DOI: https://doi.org/10.1007/3-540-36978-3

[21] P. Vicaire and J.A. Stankovic. Elastic Localization: Improvements on Distributed, Range Free Localization for Wireless Sensor Networks. Technical Report SRI Annual Report A010, Tech. Rep. CS-2004-35, University of Virginia, 2004.

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