Advanced location-based IPv6 address for the node of wireless sensor network

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ABSTRACT

Fields such as military, transportation applications, human services, smart cities and many others utilized Wireless Sensor Network (WSN) in their operations. Despite its beneficial use, occurrence of obstacles is inevitable. From the sensed data, the randomly nodes distribution will produce multiple benefits from self-configuration and regular positioning reporting. Lately, localization and tracking issues have received a remarkable attention in WSNs, as accomplishing high localization accuracy when low energy is used, is much needed. In this paper, a new method and standards-compliant scheme according to the incorporation of GPS location data into the IPv6 address of WSN nodes is suggested. The suggestion is likewise others which depends on ground-truth anchor nodes, with a difference of using the network address to deliver the information. The findings from the results revealed that perfect GPS coordinates can be conducted in the IPv6 address as well as with the transmission radius of the node, and the information is significantly adequate to predict a node's location. The location scheme performance is assessed in OMNet++ simulation according to the positioning error and the power metrics used. Moreover, some improvement practices to increase the precision of the node location are suggested.

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1. INTRODUCTION

WSNs are rapidly emanating as an important and influential factor in mobile computing [1]. Apparently, the integration of WSNs amongst computing, wireless and sensor technology has fascinated many people recently. The networks comprising a number of nodes, are facilitated with handling, communicating and sensing capabilities. WSNs which are operated using battery, consisting of cheap tiny devices of constrained processing and memory resources, is practical to measure and exchange various environmental data in their operation condition [2]. Identifying the location of sensed data and knowing the physical position of these sensor nodes are crucial to some applications [3]. However, each node needs to identify its location via one of the self-localization methods, which means estimating the unknown node position within the network [4].

The path length of mobile elements is shortened which as a result leads to minimize the energy consumption and to reduce the overall data gathering latency [5]. In order to have a longer battery lifespan, the power is utilized by taking into considerations of the unreliable radio connectivity, minimum bandwidth, small packet payload size, dynamic topology changes, ad hoc deployment, and nodes. Estimating the physical position of a sensor node within the IoT is a real challenge as it subjected to small capacity, low bandwidth, variable links, dynamic typologies, and the difficulty of battery replacement or recharging in several circumstances. On the other hand, being able to trace the source of information is crucial for various WSN applications, especially in military, environmental monitoring, and aviation for example. Nodes can be equipped with GPS, but this is a costly solution in terms of both money and energy. Cost and energy consumption are in fact the most important criteria that must be taken into account when designing the protocols and platforms of these small devices. GPS typically fails in severe environments (i.e. inside homes, offices, underground, shopping malls and between a heavy vegetative cover) [6].

This paper recommends a major design for a WSN which contains lightly distributed nodes that are small in numbers of GPS ground-truth and nodes of bigger numbers that include their location through inter-communication. The main objective of this localization process is to search for the physical position of a node (a node with obscure position) whilst utilizing reference nodes also called "ground-truth" (nodes with preconfigure locations) to obtain specific accuracy from uneven radio communication and at the same time reducing power consumption to its minimum level. The method being introduced envelops the GPS coordinates and the nominal transmission radius for a node into its IPv6 address. The objective is for a node to secure an early approximation of the node's location and also limited alternate points which are possible as its actual location. It can be achieved by listening unreceptively to the transmissions with several accurate calculations. This action will reveal the farthest distance between a node and its neighbors when the transmissions are received. The method of location is conducted and validated in OMNet++ simulation. The findings displayed that precise GPS coordinates can be conducted in the IPv6 address in addition to the transmission radius of the node.

2. LOCATION INTERPOLATION IN IPv6 ADDRESS

Requests for Comments (RFCs) is set as Internet standards by the Internet Engineering Task Force (IETF) [5]. Most of the IP-based networks depend on a one-to-one addressable flow pattern [7-8]. The IETF standard which functions to expand the use of IPv6 to WSNs is known as IPV6 over Low Power Wireless Personal Area Networks (6LoWPAN). The 6LoWPAN procedure mass contains IEEE 802.15.4 at the physical and Medium Access Control (MAC) layers, a 6LoWPAN adaptation layer, IPv6 at the network layer, and the standard Internet procedures at the transport and application layers [9-13]. Additional technologies used with 6LoWPAN include sub-GHz radios, long-range telemetry links and even power-line communications [14-15]. 6LoWPAN gateway architecture that aims to achieve end-to-end communication where Internet users can retrieve and observe real-time data [16]. 6LoWPAN has embraced the mechanism of IPv6 Stateless Address Autoconfiguration [17-20]. The WSN routing protocol usually employs data-centric routing [21] or location-based routing rather than address-centric routing that is normally used in TCP/IP networks.

The IPv6 addressing architecture which is one of its kind and designed for local communications' purpose has a special-purpose address block and IPv6 unicast address format, usually discovered inside a site. The "Unique Local IPv6 Unicast Addresses" are not supposed to be forwarded to another network on the Internet [22-24] contain general forms which are; an 8-bit prefix 0xFD00, a 40-bit Global ID set to a pseudo-random number that utilizes a standard algorithm [25] a 16-bit Subnet ID decided by the site; and a 64-bit Interface ID as displayed in Figure 1.

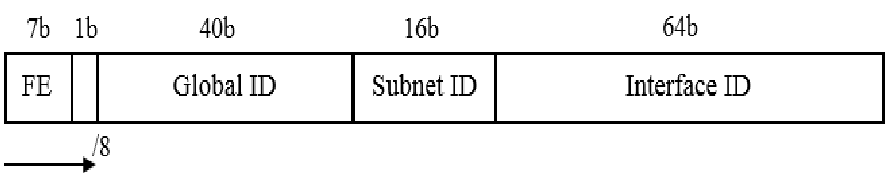


Figure 1. IPv6 unique local address [6]

In order to instill GPS coordinates in an IPv6 address, the coordinates can be moved into positive integer space. A grid of 360*180=64,800 zones were produced from 360 degrees longitude and 180 degrees latitude. The 9,999,999 offsets in each direction are derived from the seven-digit precision within each zone [25]. Basically, in a usual computer architecture representation, the latitude and longitude zone can be kept as an unsigned short integer (ushort, 16 bits), meanwhile the offsets need 24 bits of a 32-bit unsigned integer (uint). The finish coordinates could be kept in an unsigned long integer (ulong, 64 bits). Although 64 bits is the needed length for the interface recognition in an IPv6 unicast address to enable the zone and offsets to be pushed wholly into the space, an enticing possibility could happen. The 16-bit Subnet-ID field in the address permits 65,536 subnets, which can easily accommodate all the latitude/longitude zones. The two 24-bit offsets can later be positioned in the interface identifier field and the 16 bits will be used as flags [13]. The numerical part is to be recorded onto the unsigned integer grid, and the zone is joined with FD00 and the 40-bit Global-ID to shape the first half part of the address. Interleaved bits (also known as Morton numbers) are suitable for linearizing 2D integer coordinates, where x and y are merged as one number that can be compared without difficulty and also has a characteristic that a number is typically close to one another if the x value is near to the y value [25]. The new IPv6 address scheme is displayed in Figure 2.

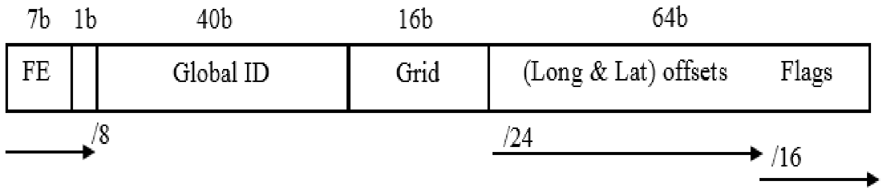


Figure 2. New IPv6 address scheme

3. EXPERIMENTS AND RESULTS

Different steps and situations are used to perform the location model and to be validated in OMNeT ver.4.1. The researcher experimental situation in the simulation is grounded on one main theory: no other network in radio range is available, in other words, there is no interference. In addition, all network nodes will be operating the identical software with no GPS attached to the nodes. Only several anchor nodes (ground-truth) will be embedded with actual GPS coordinates of their areas. However, majority of the nodes are without the coordinates. The network topology which is employed in the simulation exercises mainly begins with three fundamental Ground-Truth nodes with location coordinates (GT) which have been identified earlier and in a straight horizontal line positioning. 1000 seconds was the accumulated simulation time performance. Free space model is the best situation of the simulation of the whole experiment tests due to the absence of any hurdles of the sensing area. In the beginning, with no simulations being left out, these simulations used the OMNet++ default configuration settings and also the default configurations of the radio and within the boundary of the physical layer (Ieee802154Phy).

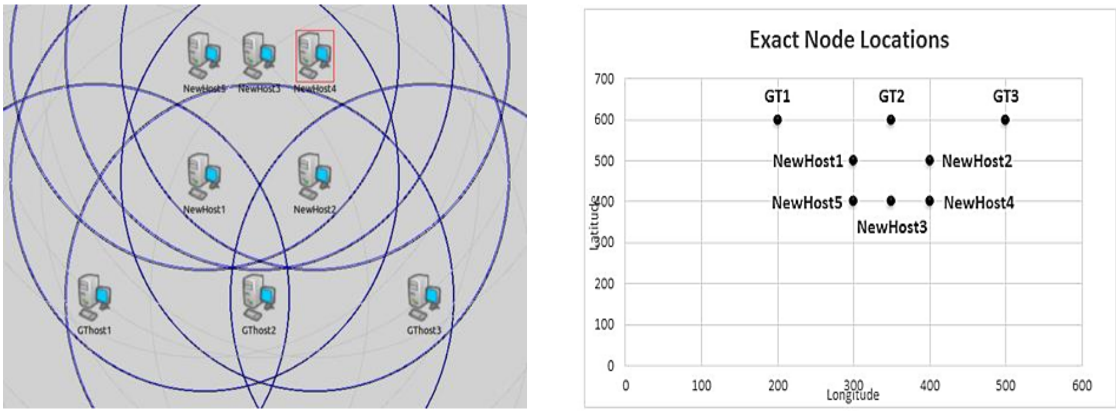
3.1. Evaluating the accuracy of the estimated nodes locations

The number of nodes and their deployment locations and implemented transmission radius were key factors for the simulation tests to evaluate the feasibility of implementing this localization model. When the simulation starting, the GTs (Ground-Truth) nodes begins to transmit ICMP Echo Request messages. The neighbouring added node after simulation run (“NewHosts”) can listen to this conversation and receive the packets that already consists of their neighbours location coordinates. Thus, the target node can implement the triangulation localization algorithm to determine its estimated location coordinates (longitude and latitude) after parsing their neighbours received addresses. To grasp the accuracy of this new location scheme, the position error between the exact coordination of the newly-added node and the approximate location is computed using the following (1):

$$Err = \sqrt{(X_{exact} - X_{est.})^2 + (Y_{exact} - Y_{est.})^2} \quad (1)$$

3.1.1. Scenario 1

The simulation network area in this scenario was 1200 $*$ 1200 meters, and the distribution (x,y) coordinates of these GT nodes in the simulation in (longitude, latitude) coordinates is illustrated in Table 1. Five new sensor nodes were added dynamically during the runtime, named from “NewHost1” to “NewHost5”. The total number of nodes in this simulation trials will be 8 sensor nodes (3 GTs and 5 unlocated nodes). The network topology of this scenario is shown in Figure 3(a). Figure 3 (b) showed all the actual positions of the basic GT nodes and the new added nodes in the simulation experiment. The obtained results from this scenario 1 shown that all newly-added nodes can be estimated their approximate location coordinates with a varied number of location errors as seen in Table 1.



(a) (b)

Figure 3. (a) Scenario 1 network topology with 8 nodes, (b) absolute node position in scenario 1

Table 1. The exact location of new added nodes in Scenario 1 with estimated locations and location errors

Node	Omnet Location	Obt. Location	Lon. Error (m)	Lat. Error (m)	location Error (m)
NewHost1	300,500	270,460	-30	-40	50
NewHost2	400,500	430,460	+30	-40	50
NewHost3	350,400	350,320	0	-80	80
NewHost4	400,400	510,320	+110	-80	136
NewHost5	300,400	190,320	-110	-80	136

The analysed results from the table shows that nodes with more neighbouring ground-truth nodes can obtain more accurate estimated locations than those nodes located further away from the original ground-truth hosts with pre-configured location coordinates. These outcomes indicate that the localization technique is not precise when using this network topology pattern (this way of nodes deployment) and within 177m of transmission radius.

- The influence of transmission radius on estimated location

As mentioned before, the network topology style and transmission radius have a real effect on the calculated locations accuracy of the sensor nodes. This happens because the implemented triangulation technique relies on finding the intersection point of the circles that continue to emit by its neighbour nodes. These circles empirically represent the actual transmission radius of the node. On the other hand, a random or specific location of the unlocated node from the intersection point of circles can also affect the accuracy of the estimated location in the network. However, the transmission power parameter was one of the key elements that is involved inside the calculation equation of the transmission radius distance for each node as shown in (2).

$$TransRadius_{distance} = \left(\frac{waveLength*waveLength*transmitterPower}{16.0*minReceivePower*M_{PI}^{2}}\right)^{1.0/alpha} \quad (2)$$

Start from that, the transmission radius in meter can be a benchmark to refine the process for estimating the locations of the node, specifically by finding the best radio transmission coverage to give the most accurate measurements of the estimated nodes locations. These factors include wavelength, transmitterPower, minReceivePower. The minimum received power (minReceivePower) refers to sensitivity, and its value equals to the sensitivity value. The wavelength value comes from the division of speed of light over the carrier frequency. As is well known, the speed of light is constant at around 3 * 108 in the communication of wireless network. As shown in Table 1 (Scenario 1), the initial results of most approximate locations for the nodes have a high location errors in one or both longitude and latitude coordinates when applying the default configuration setting of physical and radio parameter. This methodology depends on trial-and-error by adapting several parameter values inside the transmission radius (2). These factors include transmitterPower, sensitivity and carrier frequency. In the first trial test, the radio transmission power of the nodes set to the range between (0.7 and 1) mW in Scenario 1. The detailed results are shown in Table 2(a), and the results of the second portion of the trial when set transmitterPower within the range (0.6 to 0.4) mW. The modified sensitivity value or/and carrierfrequency values in the tests are in Table 2(b).

Table 2(a). Estimated locations of nodes with location error and transmission radius, changing transmission power and/or sensitivity and/or carrier frequency

TransRadius (m)	Node	Est. Loc.	Lon, Lat Error (m)	Loc. Error (m)	TrPw (mW)	Min RecPw mW	Sen dBm	Fr. GHz
177	NewHost1	270,460	-30,-40	50	1.0	$3.16228e^{-09}$	-85	2.4
(Def.)	NewHost2	430,460	+30,-40	50				
	NewHost3	350,320	0,-80	80				
	NewHost4	510,320	+110,-80	136				
	NewHost5	190,320	-110,-80	136				
141	NewHost1	270,500	-30,0	30				3
	NewHost2	400,520	0,+20	20				
	NewHost3	360,400	+10,0	10				
	NewHost4	480,430	+80,+20	82.46				
	NewHost5	230,380	-70,-20	72.80				
142	NewHost1	270,500	-30,0	30	0,8	$2.51189e^{-09}$	-86	3
	NewHost2	400,520	0,+20	20				
	NewHost3	360,400	+10,0	10				
	NewHost4	480,420	+80,+20	82.46				
	NewHost5	230,380	-70,-20	72.80				
	NewHost4	500,340	+100,-60	116.61				
	NewHost5	200,340	-100,-60	116.61				

Certainly, the nodes are located far away one hop from the base sensor hosts (ground-truth). From Tables 3 and 4, comparing with the results from Table 2, most of the nodes in the network resulted in actual improvements in the approximate locations when fitting their transmission radius to 142m or 141m rather than the original 177m. The comparison of the estimated location errors for the sensor nodes before and after optimizing the transmission radius are shown in Figure 4. A comparison of the results from the Tables 2(a) and 2(b) illustrated that the approximate locations of the nodes with the best accuracy in the estimated locations of the nodes can be gathered at radio transmission radius equal to 142 m or 141 m in the simulation. Despite these accurate outcomes of the node positions, the approximate location coordinates of the nodes are still within the location errors when using the network topology pattern of Scenario 1.

Table 2(b). Estimated locations of nodes with location error and transmission radius, changing transmission power and/or sensitivity and/or carrier frequency

TransRadius (m)	Node	Est. Loc.	Lon, Lat Error (m)	Loc. Error (m)	TrPw mW	Min RecPw mW	Sen dBm	Fr. GHz
142	NewHost1	270,500	-30,0	30	0.5	$1.58489e^{-09}$	-88	3
	NewHost2	400,520	0,+20	20				
	NewHost3	360,400	+10,0	10				
	NewHost4	480,420	+80,+20	82.46				
	NewHost5	230,380	-70,-20	72.80				
142	NewHost1	270,500	-30,0	30	0.4	$1.25893e^{-09}$	-89	
	NewHost2	400,520	0,+20	20				
	NewHost3	360,400	+10,0	10				
	NewHost4	480,420	+80,+20	82.46				
	NewHost5	230,380	-70,-20	72.80				

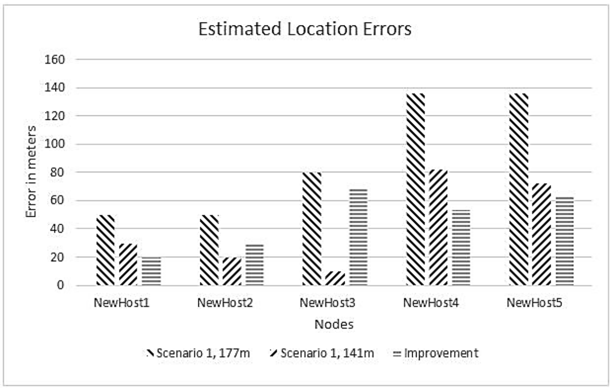
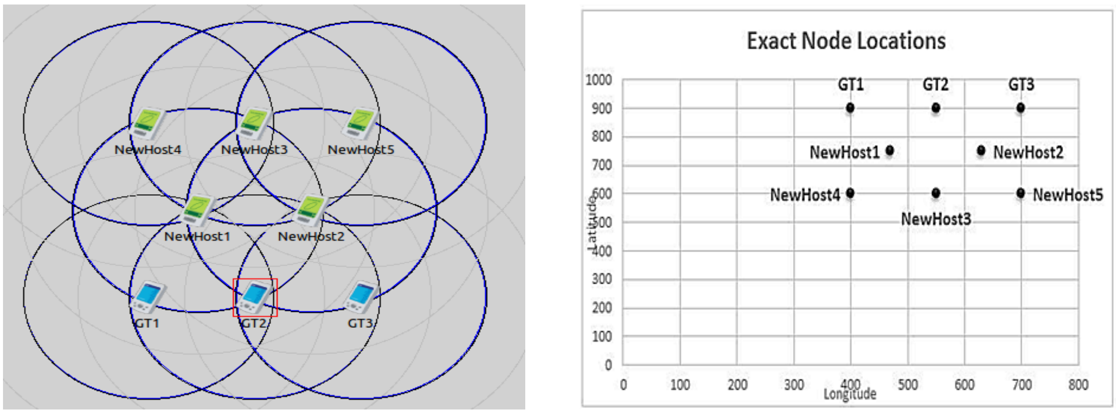


Figure 4. Approximate location errors of sensor nodes in scenario 1 before and after optimizing the transmission radius

3.1.2. Scenario 2

The simulation network in this scenario is configured with a network deployment area of 1200 x 1200 meters, and began also with three ground-truth (GT) nodes with preconfigured A data stream framework is proposed in this phase where Figure 4 shows the flow of each package between several activities designed in phase one. In the phase, it keeps pairing with the existing receiver and corresponds the communication between beacon network and user-end equipment which allows the physical transmission of data, not only connecting but also matching and packing. All the data found are resided in datalink layer and waited for further processing. Locations in a straight line. The position coordinates of these nodes are shown in Figure 5(b) and Table 5. The deployment locations of these nodes are slightly different in this network topology from the previous Scenario 1. As before, network topology comprises three straight GT nodes (with known locations). As well as, five new sensor nodes were added dynamically during simulation time without any idea about their positions as depicted in the Figure 5(a). The exact or absolute locations coordination of these sensor nodes were shown in the Figure 5(b).



(a) (b)

Figure 5. (a) Scenario 2 network topology with 8 nodes, (b) Absolute node position in scenario 2

The obtained outcomes from this trial scenario about estimating the locations of unlocalized nodes shown that all new added nodes can be measured their approximate location coordinates with a varied numbers of location errors as illustrated in Table 3, by only listening and parsing the addresses of neighbour nodes that already determined their position coordinates. Thus, implement the triangulation mechanism successfully in OMNeT++.

Table 3. The exact location of new added nodes in Scenario 2 with estimated positions and location errors

Node	Omnet Location	Obtained Location	Longitude Error (m)	Latitude Error (m)	Margin of Error (m)
NewHost1	470,750	470,760	0	+10	10
NewHost2	630,750	630,760	0	+10	10
NewHost3	550,600	550,620	0	+20	20
NewHost4	400,600	390,620	-10	+20	22.36
NewHost5	700,600	710,620	+10	+20	22.36

- The impact of network style of nodes distribution on estimated location

The network topology and the distribution positions of the sensor nodes inside the network area have actual impact on the accuracy of the approximate node location. The position of the node with regard to the presumed intersection point is very significant because the triangulation technique depends on estimating the intersection point position of the circles form by the neighbor nodes. There is a real trade-off between the used network pattern and the transmission radius of the involved nodes.

The result of the calculated node location will be very accurate and without any position error, if the unlocated node randomly or purposely lies exactly on the intersection point of the transmission radius circles. That means that the estimated location of the node will be similar to the absolute physical location of that sensor host. Both of the scenarios 1 and 2 use exactly the same configuration settings in the simulation and even apply the same transmission radius which is 177 m. The only difference was in the locations of the deployed nodes in the network.

The analysis in Scenario 1 Table 2(a) and Table 2(b) showed that the transmission radius of the node can play a crucial role on this localization scheme. Scenario 2 Table 3 showed that the distribution locations of the sensor nodes also were inappropriate in Scenario 1 network fashion, with regard to the calculations resulting from triangulation. Figure 6 shows the approximate location outcomes, Table 3 for Scenario 1 and Table 4 for Scenario 2. The conclusion of this observation test in the simulation demonstrates that network topology style and distribution manner have greater effect on the accuracy of the estimated location than just from making adjustments to the transmission radius of these nodes. Exceptionally, only the NewHost3 node recorded a downgrade in its measured location in the Scenario 2.

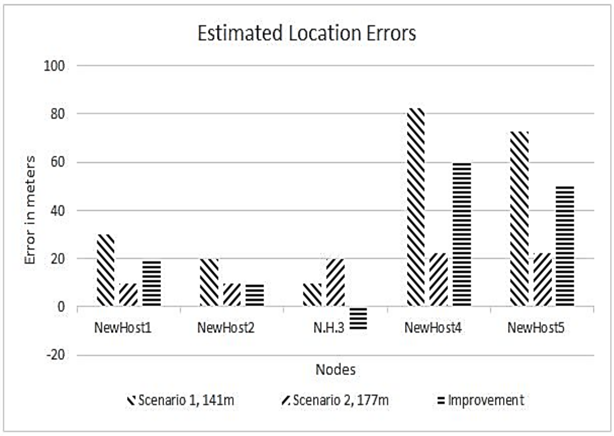
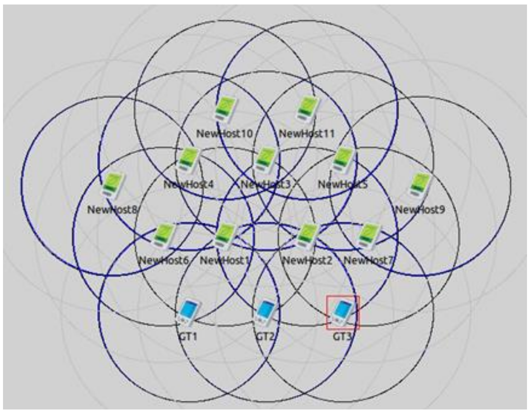


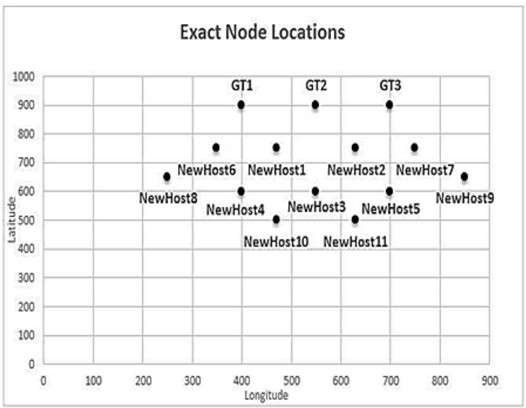
Figure 6. Estimated location errors of nodes in scenario 1 after optimizing the transmission radius and scenario 2 (adapted locations)

3.1.3. Senario 3

This scenario extends to previous Scenario 2. All the configuration settings in the simulation are the same as the configuration settings of the previous scenarios. This scenario is only different from the previous one in terms of the number of nodes, principally by increasing the number of sensor nodes to 14. The new network topology was formed from the basic GT nodes in straight horizontal line and 11 nodes were added within simulation time without any idea about their positions, as seen in Figure 7(a). All the actual coordinates of the deployed nodes in the simulation are depicted in Figure 7(b). The results from this scenario are gathered with also regard to the accuracy of the approximate locations for all sensor nodes in the network. Consequently, all the obtained location outcomes for all nodes are shown in the Table 4. The analysis of the localization results in this Table showed that all the additional appended nodes in the simulation network can estimate their positions with different location error.



(a)



(b)

Figure 7. (a) Scenario 3 network diagram with 14 nodes, (b) Absolute node locations in scenario 3

Table 4. The exact location of all added nodes in Scenario 3 with measured positions and location errors

Node	Omnet Location	Obtained Location	Longitude Error (m)	Latitude Error (m)	Margin of Error (m)
NewHost1	470,750	470,760	0	+10	10
NewHost2	630,750	630,760	0	+10	10
NewHost3	550,600	550,620	0	+20	20
NewHost4	400,600	390,620	-10	+20	22.36
NewHost5	700,600	710,620	+10	+20	22.36
NewHost6	350,750	320,760	-30	+10	31.62
NewHost7	750,750	780,760	+30	+10	31.62
NewHost8	250,650	230,630	-20	-20	28.28
NewHost9	850,650	870,630	+20	-20	28.28
NewHost10	470,500	470,490	0	-20	20
NewHost11	630,500	630,490	0	-20	20

3.2. Evaluating the consumed power for this localization model

Wireless embedded applications are characterized by low data rate (< 2Mbps), low-power (can be battery-powered for years), and their short range. The power consumption evaluation of this location model was under assumption of using the TmoteSky sensor powered by the MSP430G2x53 microcontroller. The sensor radio circuit is assumed to be CC2480. The code that is used to calculate the results was compiled, run and analyzed on Linux on an Intel Core i7-8750H. The energy consumption of this thesis localization process was audited using Perf tools that is one of Linux tools. Use the perf stat command line to get the number of CPU cycles. In fact, many CPU factors can be obtained when performing perf stat. Eventually, the power consumption for each of these three functions is individually estimated. All the resulted indications for these three functions are listed in Table 5.

Table 5. CPU factors from execution of location estimation

Function	CPU indication	Value	Note	Time (mS)
1. two audible neighbors	cycles instructions	210331 767624	0.793 GHz 0.95 ins per cycle	1.581
2. one audible neighbor with two neighbors	cycles instructions	303164 880933	0.794 GHz 0.91 ins per cycle	1.761
3. one audible neighbor with one audible neighbor	cycles instructions	215291 787594	1.387 GHz 0.91 ins per cycle	0.9338

All of these obtained results from the Table 5 may differ from CPU to others, because the architecture type of the CPU and the hardware provider have a real impact on the outcomes of these CPU indications. Actually, all of these factors are gathered under using the 64-bit CPU and most of the IoT CPU chips are built using 16- or 32-bit architectures. In addition, it relies on the kind of used compiler and the operation environment.

a. Power consumption outcomes of these localization functions

There are a number of equations used to calculate the power consumption of each location function. Firstly, the clock frequency is 16MHz with a maximum voltage of 3.5V, and the active mode current 4.5 mA, obtained from the MSP430G2x53 microcontroller datasheet. The results from the Table 6 illustrate that the power consumed of this localization scheme was small in each performed function and appropriate to these low power devices. These outcomes are not very precise and just approximate values because only a 64-bit CPU architecture is used in this test.

Table 6. Energy consumption of each location function

Function	Power Consumption (W)	Execution Time (mS)	Energy Consumption (mJ)
1. two audible neighbors		13.145	0.2070
2. one audible neighbor with two neighbors	0.01575	18.947	0.2984
3. one audible neighbor with one audible neighbor		13.455	0.2119

b. Estimation power cost compared to transmission power cost

The interval period and power cost per interval of different radio states should be calculated to compute the total power consumption of radio transmission operation. All the consumed current in various radio states are represented in Table 7. The collected results from Table 7 show that the cost of energy during transmission was very big compared with the energy consumed by the CPU to execute this localization scheme as shown in Table 6. The significance of this result is to show that several (possibly iterative) location calculations can be carried out on packets that embed the location coordinates in the address of normal communications, for the same or at a lower cost of a single beacon message dedicated to distributing location information.

Table 7. Energy consumed for each phase of the CC2480 radio transceiver for transmission

	Radio State	Power Consumption (W)	Execution Time (mS)	Energy Consumption (mJ)
Phase 1	Activate the processor, radio on	0.047	10.2	0.4774
Phase 2	Clear Channel Assessment	0.117	1.6	0.1872
Phase 3	Send data packet (2 bytes data)	0.110	0.7	0.0075
Phase 4	Receive ACK packet	0.117	1.3	0.1521
Phase 5	Commute to sleep mode	0.047	9.0	0.4212
	Total		22.9	1.2454

4. CONCLUSION

The key solution of this thesis research was to calculate the location of these unknown location nodes through their neighbour sensor hosts that already know their location and interpolated their location information in their addresses. Thus, these new nodes interpolate the location information into the IPv6 address after determining their locations with availability of minimum information. This means these position coordinates will already be included in their sending packets. Different scenarios were implemented in the OMNeT++ ver. 4.1 simulation and the results from the simulation scenarios are also gathered and analysed for this location method based on the accuracy (computation of location errors) of the measured locations and power consumption metrics.

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