METHOD AND SYSTEM IN DYNAMIC SELF-LOCALISATION FOR NON-STATIONARY IOT NETWORK AND NODES

Field of the Invention

This invention relates to a system and a method for self-locating the relative locations of non-stationary IoT and mobile nodes with respect to one single non-stationary reference node in a dynamic network topology environment and continuously determining a data signature of a particular site by the non-stationary reference node.

Prior Art

Mobile IoT networks (mIoTNs) are wireless IoT/sensor networks that consist of spatially distributed autonomous mobile sensor nodes that monitor and/or track human/objects or environmental conditions. For many mIoTN applications, the locations of the IoT node and sensor are as important as the sensed data itself. It is therefore highly desirable that the mIoTNs have inherent localisation capability to determine the locations of autonomous and mobile sensor nodes.

The key challenges that limit the pervasiveness of mobile IoT solutions are the lack of accurate, reliable and robust methods of estimating the locations of mobile IoT/sensor nodes when they are moving continuously and randomly. Current techniques restrict the anchor node (AN) to be stationary and thus reduce the operation ranges of mIoTN. Existing techniques also produce coarse location estimations, particularly for nodes at the edge of the network region. These limitations confine the potential of IoT applications and deployment.

Summary of the Invention

The above and other problems are solved and an advance in the art is made by a system and method in accordance with this invention. A first advantage of a system and

a method in accordance with this invention is that a data signature can be created and updated for an infrastructure less site by a number of mobile nodes. This allows information of the particular site to be monitored and used by the mobile nodes or others. A second advantage of a system and a method in accordance with this invention is that the data signature is continuously updated by the mobile nodes that frequent that particular site. Hence, information relevant to that particular site is monitored at least until that particular site is no longer frequented by the mobile nodes.

A first aspect of the invention describes a dynamic self-organising network recording system for a particular site. The system comprises a number of mobile nodes and an application installed on each mobile node. The application is executable on each mobile node to: determine if an anchor node is available for the particular site; in response to determining an anchor node is not available for the particular site, assign the mobile node as the anchor node, perform a setup for the particular site in order to initiate collection of data to create a data signature of the particular site, and perform continuous collection of data until a new anchor node is assigned; and in response to determining an anchor node is available for the particular site, respond according to request from the anchor node.

According to an embodiment of the first aspect of the invention, the step to perform the setup for the particular site in order to initiate collection of data to create the data signature of the particular site comprises the application to: determine an operating environment; and check availability of cross layer Performance Reference Profiles (PRP) for the corresponding operating environment.

According to an embodiment of the first aspect of the invention, the step to perform the setup for the particular site in order to initiate collection of data to create the data signature of the particular site further comprises the application to: in response to no cross layer PRP available, conduct a wireless site survey.

According to an embodiment of the first aspect of the invention, the step to conduct a wireless site survey comprises the application to: create a layout map of the particular site; record other mobile nodes in the particular site as non-anchor node; create a layout plan according to the particular site; define zones of each of the non-anchor nodes with respect to the anchor node location; and scan and collect, from each of the non-anchor nodes, all performance parameters values from one or more of system, device, link, network, application level to create a data signature of the particular site.

According to an embodiment of the first aspect of the invention, the step to create the data signature of the particular site comprises the application to: determine statistical values for all performance parameters values obtained through wireless site survey in blocks of predetermined period for all zones.

According to an embodiment of the first aspect of the invention, the step to perform continuous collection of data until a new anchor node is assigned comprises the application to: obtain data from the non-anchor nodes, the data includes performance parameters values from one or more of system, device, link, network, application level, and connectivity of each non-anchor node with neighbouring nodes within the particular site.

According to an embodiment of the first aspect of the invention, the step to perform continuous collection of data until a new anchor node is assigned comprises the application to: obtain data from the non-anchor nodes, the data includes performance parameters values from one or more of system, device, link, network, application level, and connectivity of each non-anchor node with neighbouring nodes within the particular site; determine a score for each of the mobile nodes; determine whether the score for the anchor node is below a pre-determined threshold; and in response to determining the score for the anchor node is below a pre-determined threshold, assign a new anchor node.

According to an embodiment of the first aspect of the invention, the step to determine a score for each of the mobile nodes comprises the application to: assign a locality score, $Score_L$, to each mobile node based on the location of each of the mobile nodes within the boundary of the site with respect to a centroid location; assign a connectivity score, $Score_C$, to each mobile node based on connectivity with neighbouring nodes; assign a reliability score, $Score_R$, each mobile node based on the reliability determined which is a probability of any two nodes having an operative path connecting them; determine the score for each mobile node with the following expression, $Score_T = Score_L + Score_C + Score_R$); and store $Score_T$ of each mobile node.

According to an embodiment of the first aspect of the invention, the step to assign a new anchor node comprises the application to: assign the mobile node with the highest $Score_T$ as the new anchor node; notify the new anchor node to take over as the anchor node; and transmit the data signature of the particular site and all data received to the new anchor node.

A second aspect of the invention describes a dynamic self-organising network recording method for a particular site having a number of mobile nodes. The method comprising: determining if an anchor node is available for the particular site; in response to determining an anchor node is not available for the particular site, assigning the mobile node as the anchor node, performing a setup for the particular site in order to initiate collection of data to create a data signature of the particular site, and performing continuous collection of data until a new anchor node is assigned; and in response to determining an anchor node is available for the particular site, responding according to request from the anchor node.

According to an embodiment of the second aspect of the invention, the step of performing the setup for the particular site in order to initiate collection of data to create the data signature of the particular site comprises: determining an operating environment;

and checking availability of cross layer Performance Reference Profiles (PRP) for the corresponding operating environment.

According to an embodiment of the second aspect of the invention, the step of performing the setup for the particular site in order to initiate collection of data to create the data signature of the particular site further comprises: in response to no cross layer PRP available, conducting a wireless site survey.

According to an embodiment of the second aspect of the invention, the step of conducting a wireless site survey comprises: creating a layout map of the particular site; recording other mobile nodes in the particular site as non-anchor node; creating a layout plan according to the particular site; defining zones of each of the non-anchor nodes with respect to the anchor node location; and scanning and collecting, from each of the non-anchor nodes, all performance parameters values from one or more of system, device, link, network, application level to create a data signature of the particular site.

According to an embodiment of the second aspect of the invention, the step of creating the data signature of the particular site comprises: determining statistical values for all performance parameters values obtained through wireless site survey in blocks of predetermined period for all zones.

According to an embodiment of the second aspect of the invention, the step of performing continuous collection of data until a new anchor node is assigned comprises: obtaining data from the non-anchor nodes, the data includes performance parameters values from one or more of system, device, link, network, application level, and connectivity of each non-anchor node with neighbouring nodes within the particular site.

According to an embodiment of the second aspect of the invention, the step of performing continuous collection of data until a new anchor node is assigned comprises: obtaining data from the non-anchor nodes, the data includes performance parameters values from one or more of system, device, link, network, application level, and connectivity of each non-anchor node with neighbouring nodes within the particular site;

determining a score for each of the mobile nodes; determining whether the score for the anchor node is below a pre-determined threshold; and in response to determining the score for the anchor node is below a pre-determined threshold, assigning a new anchor node.

According to an embodiment of the second aspect of the invention, the step of determining a score for each of the nodes comprises: assigning a locality score, $Score_L$, to each mobile node based on the location of each of the mobile nodes within the boundary of the site with respect to a centroid location; assigning a connectivity score, $Score_C$, to each mobile node based on connectivity with neighbouring nodes; assigning a reliability score, $Score_R$, each mobile node based on the reliability determined which is a probability of any two mobile nodes having an operative path connecting them; determining the score for each mobile node with the following expression, $Score_T = Score_L + Score_C + Score_R$); and storing $Score_T$ of each mobile node.

According to an embodiment of the second aspect of the invention, the step of assigning a new anchor node comprises: assigning the mobile node with the highest $Score_T$ as the new anchor node; notifying the new anchor node to take over as the anchor node; and transmitting the data signature of the particular site and all data received to the new anchor node.

Brief Description of the Drawings

The above and other features and advantages in accordance with this invention are described in the following detailed description and are shown in the following drawings:

Figure 1 illustrating an anchor point moving to the another location;

Figure 2 illustrating a block diagram of components in a network interface; and

Figure 3 illustrating a process of selecting an anchor node in accordance with an embodiment of this disclosure;

Figure 4 illustrating an example of refining the location for far end nodes in accordance with an embodiment of this disclosure;

Figure 5 illustrating a process to elect a new anchor node and transferring of the data signature to the new anchor node;

Figure 6 illustrating assigning a new AN based on the movement of the nodes within the boundary of the site;

Figure 7 illustrating the raw network parameters collected for a particular site;

Figure 8 illustrating the raw network parameters collected for a particular site being stored in a particular format;

Figure 9 illustrating the calculation of the mean of the RSSI;

Figure 10 illustrating the calculation of the mean of the Bit Rate;

Figure 11 illustrating the calculation of the mean of the link quality; and

Figure 12 illustrating the calculation of the mean of the Round trip time.

Detailed Description

This invention relates to a system and a method for self-locating the relative locations of non-stationary IoT and mobile nodes with respect to one single non-stationary reference node in a dynamic network topology environment and continuously determining a data signature of a particular site by the non-stationary reference node.

It is envisioned that a system and a method in accordance with embodiments of this invention is capable of enabling location determination of neighbouring IoT nodes by a moving (non-stationary) anchor node in an infrastructure-less network, determine location of devices based on a real-time updated cross-layer performance reference profiles (PRP), refining the data of the location for far-end nodes and select and re-elect moving (non-stationary) anchor node in a dynamic network topology environment. The data collected by an anchor node are stored and transmitted to a new anchor node when the previous anchor node is unable to continue as the anchor node for a particular site.

Such continuous collecting and storing of data of a particular site creates a data signature of the particular site and allows one to use the data signature. For purposes of this disclosure, the particular site is an infrastructure-less network such as mIoTNs. Hence, this disclosure pertains to creation of ad-hoc network by random non-stationary nodes to determine a data signature of the particular site.

The system and method implements cross-layer performance reference profiles (PRP) which are induced by an anchor node (AN) to uniquely define the data signatures that determine pockets of areas within the mobile IoT network (mIoTN) region. Advantageously, the need of a stationary AN is eliminated with the inclusion of real-time updates of PRP by the neighbouring nodes while the AN is moving. With this, the system and method according to this disclosure is capable of providing a free ranging mIoTN region which effectively moves as the AN is given the freedom to move. The method and system according to this disclosure uses system, network and application layer parameters to form cross-layer PRP that have higher resolution, accuracy, and reliability. The method and system according to this disclosure also provides a way to refine the estimates of the locations of the nodes at the edge of mIoTN region with the assistance of neighbouring mobile nodes that have location stability.

The method and system according to this disclosure uses one AN as the primary reference for the entire mIoTN and the AN is freely mobile, which is termed mobile AN. The method and system according to this disclosure will allow flexible operating boundary since the AN can be mobile, unlike the current circumstances where the AN has to be stationary as this will restrict the operating region to be within the signal boundary of the stationary AN.

Figure 1 illustrates an anchor IoT node 104 moving to a new location 104'. In such circumstances, the IoT nodes 105-109 may not be able to connect to the anchor IoT node 104'. As mentioned previously, for many mIoTN applications, the locations of the IoT node and sensor are as important as the sensed data itself. It is therefore highly desirable

that the mIoTNs have inherent localisation capability to determine the locations of autonomous and mobile sensor nodes.

Each IoT node comprises a network interface as described below to execute instructions according to the method and system according to this disclosure.

For the purpose of this discussion, the term “Internet of Things” (IoT) device refers to any apparatus having a communication interface to allow transferring and receiving of information among the IoT devices over a wired or wireless connection. IoT devices comprise, but not limited to, sensor devices, embedded systems, network-based cameras, gateways, mobile phones, computers, laptops, personal digital assistants (PDAs), white goods, appliances, etc.

For embedded systems, gateways, mobile phones, computers, laptops, PDAs, and mobile devices, such IoT nodes are typically equipped with wireless network interface (e.g. Bluetooth, Wi-Fi, Wi-Fi Direct, Long-Term Evolution (LTE) Direct, RF antenna, etc.) or wired network interface (e.g. an Ethernet connection, a USB or Firewire connection, etc.) to allow transferring and receiving of data.

For white goods such as fridge and washing machine, such appliances may not be equipped with any wired or wireless network interface. Hence, it is common that a network interface module be provided to allow such appliances to be communicatively connected to the Internet so that one is able to control the appliances.

Figure 2 illustrates the block diagram of a basic network interface 200. The network interface 200 can receive and transmit data, execute software applications. Network interface 200 comprises a processor 210, memory 220, transceiver 230 and input/output ports 240.

The processor 210 is a processor, microprocessor, microcontroller, application specific integrated circuit, digital signal processor (DSP), programmable logic circuit, or other data processing device that executes instructions to perform the processes in

accordance with the present invention. The processor 210 has the capability to execute various applications that are stored in the memory 220.

The memory 220 may include read-only memory (ROM), random-access memory (RAM), electrically erasable programmable ROM (EEPROM), flash cards, or any memory commonly used for computers.

One or more input/output (I/O) ports 240 can be configured to allow the processor 210 to communicate with and control from various I/O devices for the IoT devices. Peripheral devices that may be connected to network interface 200 via the I/O ports 240 include a USB storage device, an SD card or other storage device for transmitting information to or receiving information from the network interface 200. In addition to updating applications stored on memory 220 or installing new applications onto the memory via the transceiver 230, a user may alternatively install new applications or update applications on the memory 220 through a user interface such as a USB via the I/O ports 240.

One skilled in the art will recognize that other features may be included in the network interface 200. Further, the components in network interface 200 may be replaced by other components that perform similar functions. In brief, the network interface 200 as shown in figure 2 is considered merely illustrative and non-limiting.

In accordance with embodiments of this disclosure, instructions executable by the processor of network interface 200 or typical network interface provided in IoT devices are stored in respective memory. One skilled in the art will recognize that the instructions may be stored and/or performed as hardware, firmware, or software without departing from this disclosure.

For purposes of this disclosure, the same or equivalent wireless network interfaces are installed on each of the mobile nodes. This is to ensure that the data collected are consistent and accurate. For example, wireless network interfaces produced by different manufacturers may have different signal strength. Hence, the data collected

may cause irregularities in the data signature of a particular site and may render the data collected useless.

Accordingly, an application is being installed in each of the IoT nodes having the same or equivalent wireless network interface. In other words, the processes according to this disclosure are being executed by an application installed on the memory of the IoT nodes.

At the initial stage, users have to choose an anchor node. This can be decided based on which node will be placed at the centroid of the network region, more CPU power and memory, etc. The re-election of new anchor node will only take place when the current anchor node is drifted too far away from the neighbouring nodes, battery power is too low and at risk of shutting down, slow response, resource threshold exceeded, the number of connectivity from neighbouring nodes drop to below a pre-determined threshold or other condition that the user decided on. Alternatively, the AN can be dynamically selected among the list of AN candidates with known locations. Particularly, scores of the AN candidates in this process are based on their distances from the centroid of the mIoTN which moves as the autonomous sensor nodes move that also includes the number and reliabilities of the connectivity with its neighbouring nodes. Higher scores are given to the nodes closer to the centroid location, higher number of connectivity and better reliabilities. The node with the highest score will be selected as the AN. In another embodiment for selecting an anchor node, each node would transmit details of their resources to other connected nodes. The details of the resources include memory capacity, processor capacity, battery life, the number of existing connectivity of neighbouring nodes and their reliabilities, etc. With the information on the resources, process 300 would determine whether its resources are ranked the highest among the nodes. If its resources are not ranked the highest among the nodes, the node would not proceed further with process 300 and wait for further instruction from an anchor node which is the one with resources that has highest ranking. If its resources are ranked the

highest among the nodes, process 300 defines the node as the anchor node and transmits a response to other nodes to install them as non-anchor node.

For purposes of this description, IoT node may be used interchangeably with mobile node.

Figure 3 illustrates a process 300 performed by a mobile node according to the system and method of this disclosure. Process 300 begins with step 305 by setting up the mobile node. Particularly, a user has to install the application on the mobile node to perform the processes according to this disclosure in order for dynamic self-organising network to record and continuously update a data signature for a particular site. After installing the application, the user has to define and select a type of the IoT node (e.g. IoT gateways, wireless sensor controllers, IoT embedded systems, IoT sensors, etc), type of mobile devices (e.g. tablet, phones, etc.) and wireless technologies to be used (e.g. wifi, zigbee, etc.) The user also has to install necessary drivers, self-organising network protocols and engine into the above IoT nodes and devices. This can be done by a prompt box asking the user to input the necessary selection.

In step 310, process 300 determines the operating environment, create layout map and check cross layer PRP. Assuming the mobile node is a genesis node and that no anchor node has been elected for the particular site, the user has to select choice of operating environment and create/scan layout map for the particular site and check the availability of cross-layer Performance Reference Profiles (PRP) for equivalent operating environment. The layout map of the particular site may be manually created by the user. Alternatively, if the floor plan of the site is available online, the user may retrieve the floor plan and install the floor plan to the mobile device. Operating environments include commercial buildings, educational institutes, manufacturing plants, basements of buildings and indoor carparks, *etc.* The data that are required for each operating environment may vary. Hence, a PRP template may be provided for each operating environment.

In step 315, if there is no PRP or wireless site survey (or equivalent virtual site survey or simulation test results are not available) being done for the same/similar environment previously, process 300 proceeds to step 320 to conduct wireless site survey.

In step 320, process 300 conducts wireless site survey in the following manner. First, process 300 defines the mobile node as the anchor node and scan for other mobile nodes within the particular site. If there are other IoT nodes and mobile devices, these nodes will be recorded as non-anchor node. Process 300 then draws or creates a layout plan and defines zones of each of the non-anchor nodes with respect to the anchor node location. See figure 4 where four nodes 401-404 are determined in the layout plan 400 of the infrastructure-less site with four zones 410-440. Thereafter, process 300 scans network and collects, from each of the nodes in the ad-hoc network, all performance parameters values from system / device / link / network / application level (e.g. RSSI, link quality, packet round-trip time, application performance response time, etc.). The performance parameters would be used to create a data signature of the site.

In step 325, process 300 determines cross-layer PRP in the following manner. Particularly, process 300 determines statistical values (mean, standard deviation, etc.) for all performance parameters values obtained through wireless site survey in a block of minutes defined, for all zones. Thereafter, process 300 determines the uniqueness of multiple range of statistical values to form the cross-layer PRPs, which represents the unique location signatures of these zones. See figure 4 illustrating four zones 410-440 where first node 401 is in zone 410, second node 402 is in zone 420, third node 403 is in zone 430, and fourth node 404 is in zone 440. After step 325, process 300 proceeds to step 330. Further details on the process of determining cross layer PRP will be described below.

In step 330, process 300 stores PRP in the memory of the anchor node. The PRP is essentially the data signature of the site.

Steps 310-330 are performed on the basis that the mobile node is a genesis node and that no anchor node has been elected for the particular site. Hence, the mobile node has to perform the setup for the particular site in order to initiate the collection of data to create the data signature of the particular site. If an anchor node is available, the mobile node would respond to the anchor node accordingly so that the anchor node can collect the required data accordingly in order to generate the data signature of the particular site. Otherwise, the mobile node would proceed with steps 310-330 to obtain the necessary information to generate a data signature for the particular site. In other words, an additional step may be provided between step 305 and step 310 to determine whether an anchor node is available. If the mobile node determines that an anchor node is not available for the particular site, the mobile node will be assigned as the anchor node and proceed with step 310. If an anchor node is available, the mobile node will respond according to request from the anchor node.

In step 340, the anchor node initiates the formation of self-organising network with all IoT nodes and mobile devices. The formation of self-organising network can be implemented following closely the IETF - Mobile Ad-hoc Network (MANET) standards such as OLSR, DSDV, AODV, DSR, etc.

In step 350, process 300 performs continuous collection of data until a new anchor node is assigned. The continuous collection of data may be initiated for every interval of a time period that is predetermined by a user. The anchor node will perform network scan, collect performance values from multiple layers, calculate the statistical values, and determine the Performance Profiles (PP) for each node. In particular, the data to be obtained by the anchor node includes all performance parameters values from system / device / link / network / application level (e.g. RSSI, link quality, packet round-trip time, application performance response time, etc. Further, the AN would also request for connectivity of each mobile node. In response, the mobile node has to scan and determine the neighbouring nodes that are connectable to the mobile node within the

boundary of the particular site. During this step, a new AN may be selected and further details will be described below with reference to figures 5 and 6. Alternatively, step 350 is initiated when the active AN deviates too far away from its current location by certain distance.

Process 300 ends after step 350. For example, process 300 ends when the mobile nodes that frequent that particular site no longer enter that particular site for a pre-determined time period.

Selection and Re-election of anchor node

In order to ensure continuity of the collecting and preserving of the data signature of the particular site, the anchor node has to forward the data signature to another anchor node as and when required. For example, re-electing of anchor node is required when the anchor node moves out of the vicinity of the particular site, when the battery of the anchor node is running low, etc.

The AN is required to obtain the required data from all the mobile nodes within the particular site as required in step 350 in process 300. The required data includes all performance parameters values from system / device / link / network / application level (e.g. RSSI, link quality, packet round-trip time, application performance response time, etc. Further, the AN would also request for connectivity of each mobile node. In response, the mobile node has to scan and determine the neighbouring nodes that are connectable to the mobile node within the boundary of the particular site. The number of connected neighbouring nodes of each node and the reliabilities of each connection are also recorded.

The AN can be user selectable, or dynamically elected among the list of AN candidates with known locations. Figure 5 illustrates a process 500 performed by an anchor node according to the system and method of this disclosure to continuously collect data and update the data signature until a new anchor node is assigned. Process

500 includes re-electing a new anchor node and transferring of the data signature to the new anchor node. Particularly, scores of the AN candidates in the election process are based on their distances from the centroid of the mIoTN which moves as the autonomous sensor nodes move. Higher scores, $Score_L$, are given to the nodes closer to the centroid location, $Score_C$ for higher number of existing connectivity to neighbouring nodes and $Score_R$ for higher reliabilities of the existing connectivity. The node with the highest score will be elected as the AN. Re-election process occurs when the active AN deviates too far away from the centroid of the mIoTN, drop in the number of connectivity with its neighbouring nodes and the reduction of reliabilities of the connectivity that cause its relative score, $Score_T$ ($Score_T = Score_L + Score_C + Score_R$) falls below a predetermined threshold.

Process begins with step 505 to obtain the required data, as mentioned above, from all mobile nodes within the boundary of the site. The detailed step of obtaining the required data are well known and hence omitted for brevity.

In step 510, upon receiving the required data, process 500 determines a score for each of the mobile nodes in the following manner.

First, the AN determines the location of each of the mobile nodes within the boundary of the site. Based on the location, a locality score, $Score_L$, is assigned to each node. Particularly, the node closer to the centroid location is given a higher score and the node farthest the centroid location is given a lowest score. The locality score is normalised according to the number of mobile nodes within the boundary of the site.

Secondly, the AN determines the connectivity of each node. For example, the connectivity of the anchor node may be expressed in the following manner.

Connectivity = $\{Node_i, Node_{i,i}\}$

Where i = 1….n, $Node_i$ refers to mobile node in direct connectivity with the node and $Node_{i,i}$ refers mobile node in indirect connectivity with the node. For example, $Node_1$ with connectivity of $\{Node_2, Node_3, Node_{2,4}, Node_{3,5}\}$ would refer to being in direct

connectivity with $Node_2$ and $Node_3$, $Node_4$ is connectable to $Node_1$ via $Node_2$, and $Node_5$ is connectable to $Node_1$ via $Node_3$.

A connectivity score, $Score_C$, is assigned to the mobile node based on its connectivity with neighbouring nodes. Particularly, the node with the highest number of connectivity to neighbouring nodes is assigned a higher connectivity score while the node with the least number of connectivity to neighbouring nodes is assigned the lowest connectivity score. For example, a score of 1 would be given for each direct connectivity and 0.5 would be given for each indirect connectivity. The connectivity score is normalised according to the number of mobile nodes within the boundary of the site.

Thirdly, the AN determines the reliability for each node. The reliability is a measure of the probability that any two nodes of the network have an operative path connecting them. Particularly, the distance between two nodes and the other node and signal to noise ratio between the two nodes can be used to determine the reliability. One method of determining reliability of each node with multiple paths is based on the algorithm presented in Section 2.3 of D. K. Panda and R. K. Dash, "Reliability Evaluation and Analysis of Mobile Ad Hoc Networks," *International Journal of Electrical and Computer Engineering (IJECE),* vol. 7, pp. 479-485, 2017.

A reliability score, $Score_R$, is assigned to each mobile node based on its reliability determined. In this step, the node with the highest reliability value is assigned a higher reliability reliability score while the node with the least reliability value is assigned the lowest reliability score. The reliability score is normalised according to the number of mobile nodes within the boundary of the site.

Lastly, the total score for each mobile node is determined with the following expression, $Score_T$ ($Score_T = Score_L + Score_C + Score_R$).

In step 515, process 500 determines whether the total score for the AN is below a pre-determined threshold. This step is required to determine whether the AN is still capable of performing its role as an AN. For example, if the AN deviates too far away

from the centroid of the site, drop in the number of connectivity with its neighbouring nodes and the reduction of reliabilities of the connectivity, a low total score would infer that the AN is no longer capable of performing its role as an AN. If the total score for the AN is below a pre-determined threshold, process 500 proceeds to step 520 to assign a new anchor node. If the total score for the AN is above the pre-determined threshold, process 500 repeats from step 505 to obtain the required data in the next interval.

In step 520, process 500 assigns a new anchor node based on the total score of each of the mobile nodes. Specifically, the mobile node with the highest total score will be assigned as the new AN. The current AN assigns a new AN in the following manner.

The current AN notifies the new AN to take over as the AN. In response, the new AN acknowledges the notification and wait for further details. The current AN upon receiving the acknowledgement from the new AN, transmits the data signature of the site and all data received (required to update the data signature) to the new AN. The current AN then transmits a notification to the rest of the mobile node that a new AN has been assigned.

Process 500 ends after step 520.

Optionally in step 515, the trigger to elect a new anchor node may be based on battery level, or one or more of the scores ($Score_L$, $Score_C$, $Score_R$) being below a predetermined threshold. Figure 6 illustrates assigning of a new AN based on the movement of the nodes within the boundary of the site. Particularly, when AN 104 moves away from the centroid of the site, AN 104 hands over the data signature of the site to the new AN 105.

After the AN is identified, a PRP is mapped onto its location to uniquely define signatures that determine pockets of areas within the site. Locations of the mobile nodes are initially estimated through these reference signatures and later updated via the location refinement techniques (described below) to improve accuracies.

An important inclusion in the algorithm that keeps the PRP current and relevant is the real-time feedback and updates of performance parameter values from the mobile nodes. As AN moves, the PRP makes the same translational movement relative to the AN, albeit with slight modification. Concurrently, the mobile nodes continue their location refinement process together with their real-time measurement of performance parameters. With the real-time updates of new estimated locations and their corresponding new performance reference data of the mobile nodes, the vector-shifted PRP improves as time goes. This process also applies when a new AN is elected.

In the event that the AN is the only node within the boundary of the site and the AN is no longer able to perform its duty as an AN (i.e. due to low battery level, moving out of the boundary of the site, etc), the AN has to engage the AN of neighbour sites to transfer the data signature to one of more of the AN of the neighbour sites. This is to ensure continuity of the collection of data signature of the particular site. Otherwise, a central server may be provided to store the data signatures of all sites. However, in order for this to be self-sustainable, it is preferred that the AN of neighbouring sites are engaged to store the data signature.

Essentially, the creating and continuous collecting of data signature of a particular site is required as regular mobile nodes visit the particular site. Hence, the probability of the particular site having no mobile node is low. Nevertheless, in the event that such scenario arises, the data signature is transferred and stored with the AN of neighbouring sites.

Cross-layer Performance Reference Profile (PRP)

Conventional methods that use only system layer parameters, such as received signal strength indicator (RSSI), time of arrival (ToA), angle of arrival (AoA) or time difference of arrival (TDoA), to localise mobile nodes are sensitive to changes in environmental conditions. To improve accuracy and reliability of location estimation, the

method and system according to the disclosure uses a combination of system, network and application performance parameters as location signatures for initial localisation of mobile nodes. The different layer performance parameters respond differently to any specific condition changes in the environment such as network congestions, nodes density, application impacts, etc., and thus provide a more stable and reliable, as well as higher resolution profile.

System profile parameters are obtained by using well-known system parameters such as RSSI, ToA, AoA, or TDoA. Network profile parameters are obtained by using network response time, packet round trip propagation delay or packet error rate. Application profile parameters are obtained by using the application response time of a pre-determined applications, messages or file transfers.

The initial PRP is generated through the use of propagation models, simulation and field test results.

The disclosure uses statistical values of mean, average and standard deviation for the parameters of Received Signal Strength Indicator (RSSI), link quality, packet round-trip time, and message turn-around time in defining the PRP. Higher score (i.e. more significant one) is given to the RSSI, follow by link quality, packet round-trip time, and message turn-around time (E,g. RSSI[0.4], link quality [0.3], packet round-trip time [0.2] and message turn-around time [0.1], where the bracket indicates the weightage assigned to the relevant parameters). A higher weighted value is assigned to the mean, followed by the average and the standard deviation of each parameter. Different sets of unique statistical values of the above parameters obtained will be used to characterise different region of areas with respect to the anchor node.

The PRP collection process can be illustrated using the data shown in figures 7-12 where total PRP collection period spanned over a period of four weeks for three sites, recorded by respective anchor nodes. Each week was divided into five weekdays (*i.e.*, Monday to Friday) and within each day, it was divided into three timeslots (*i.e.*, 9am to

12pm, 12pm to 3pm and 3pm to 6pm). The *RSSI*, Bit Rate (*BR)*, Link Quality (*LQ)* and Round trip time (*RTT)* of each location were recorded for 15 minutes at each location and the mean of each parameters ($\overline{RSSI}$, $\overline{BR}$, $\overline{LQ}$ and $\overline{RTT}$) were calculated by respective anchor nodes and uploaded to a common database. In total, there were more than 480,000 network parameters collected during the 4 weeks, 20 days and 60 timeslots of the three locations. Figure 7 show the raw network parameters captured for a particular site during one of the Mondays for the 9am to 12pm timeslot. Figure 8 shows the raw data that are needed to evaluate the mean of each parameter, namely $\overline{RSSI}$, $\overline{BR}$, $\overline{LQ}$ and $\overline{RTT}$. The raw data are stored using the database schema: *Day*, *Timeslot*, *Location*, $RSSI$, BR, LQ and RTT. The mean of each parameter are presented in figures 9 to 12. Figure 9 illustrates the calculation of the mean for *RSSI* over a particular timeslot. Figure 10 illustrates the calculation of the mean for *BR* over the particular timeslot. Figure 11 illustrates the calculation of the mean for *LQ* over the particular timeslot. Figure 12 illustrates the calculation of the mean for *RTT* over the particular timeslot.

One skilled in the art will recognise that other data collection method and parameters may be implemented without departing from the disclosure and the above described only present one possible method for collecting and determine a data signature of a particular site.

<u>Location Refinement for Far-End Nodes</u>

Far-end node is defined as a mobile node that is located near the edge of the AN coverage area. Communication links between the anchor node and the far-end nodes are weak and unreliable as the signal strengths received at either end are near the threshold level. Any deterioration in the received signal strength due to changing environmental condition will cause link connectivity to be dropped.

A reference node is defined as a mobile node that can be used to perform location estimation. The requirements for a reference node are location stability, sufficient power

availability, proximity and good link connectivity with the respective far end node. To localise a far end node, two reference nodes (for 2D localisation) are selected by the AN from a list of reference node candidates based on the above criteria. As shown in figure 4, node N_2 402 and node N_3 403 are selected by the AN (N_1) 401 to be the reference nodes for far end node N_4 404. In this example, the boundary of the site is defined by 410-440.

At discrete time interval T=t, the coordinate location $L_{4,t}$ (x4,t , y4,t) of mobile node N_4 are computed by 2 neighbouring reference nodes N_2 and N_3 as the following Loci intersection:

$$| L_{4,t} - L_{2,t-1} | = d_{24,\,t} \qquad (1)$$

$$| L_{4,t} - L_{3,t-1} | = d_{34,\,t} \qquad (2)$$

Where $d_{mn,t}$ denotes the estimated Euclidean distance between reference nodes Nm and far end node Nn at time t, and

$L_{m,t}$ denotes the computed coordinate location for far end node Nm at time t.

The solution with the minimum distance from the previous estimated location $L_{4,t-1}$ is accepted. In other words, at time t, where N_4 404 moves to the new location 404', N_4 would be selected as the new anchor node.

With the location refinement techniques, mobile sensor nodes that moves outside the AN coverage area can also be located. Further, this refinement technique can also be used in conjunction with calculating the reliability of a mobile node as the path (which is a sequence of mobile nodes through which the information is related from the anchor node) in the ad-hoc network can be established.

Industrial Applications

Internet of Things (IoT) is projected to be one of the fastest growing technology segments in the next 3 to 5 years and is expected to grow to $290 billion by 2017. For most IoT applications, the location of the IoT node is as important as the sensed data or information provided. In tandem with the growth of massive use of IoT nodes and

emerging mobile IoT applications, key challenges exist in the practicality of locating IoT nodes in densed nodes deployment without additional hardware for location determination, and locating IoT nodes while the reference or anchor node itself is non-stationary or mobile.

The proposed novel method can be developed as a software engine or as a development platform supporting innovative IoT location-services development will have great market potential and business opportunities across vast industry verticals such as health-care, smart building, disaster control, etc. covering human networks, human to machine networks and machine to machine networks.

The above is a description of exemplary embodiments of a system and method for determining a new anchor node where the anchor node is non stationary in accordance with this disclosure. It is foreseeable that those skilled in the art can and will design alternative systems and methods based on this disclosure.

Claims

1. A dynamic self-organising network recording system for a particular site comprising:

a plurality of mobile nodes;

an application installed on each of the plurality of mobile nodes, the application executable on each of the plurality of mobile nodes to:

determine if an anchor node is available for the particular site;

in response to determining an anchor node is not available for the particular site, assign the mobile node as the anchor node, perform a setup for the particular site in order to initiate collection of data to create a data signature of the particular site, and perform continuous collection of data until a new anchor node is assigned; and

in response to determining an anchor node is available for the particular site, respond according to request from the anchor node.

2. The dynamic self-organising network recording system according to claim 1 wherein the step to perform the setup for the particular site in order to initiate collection of data to create the data signature of the particular site comprises the application to:

determine an operating environment; and

check availability of cross layer Performance Reference Profiles (PRP) for the corresponding operating environment.

3. The dynamic self-organising network recording system according to claim 2 wherein the step to perform the setup for the particular site in order to initiate collection of data to create the data signature of the particular site further comprises the application to:

in response to no cross layer PRP available, conduct a wireless site survey.

4. The dynamic self-organising network recording system according to claim 3 wherein the step to conduct a wireless site survey comprises the application to:

create a layout map of the particular site;

record other mobile nodes in the particular site as non-anchor node;

create a layout plan according to the particular site;

define zones of each of the non-anchor nodes with respect to the anchor node location; and

scan and collect, from each of the non-anchor nodes, all performance parameters values from one or more of system, device, link, network, application level to create a data signature of the particular site.

5. The dynamic self-organising network recording system according to claim 4 wherein the step to create the data signature of the particular site comprises the application to:

determine statistical values for all performance parameters values obtained through wireless site survey in blocks of predetermined period for all zones.

6. The dynamic self-organising network recording system according to claim 1 wherein the step to perform continuous collection of data until a new anchor node is assigned comprises the application to:

obtain data from the non-anchor nodes, the data includes performance parameters values from one or more of system, device, link, network, application level, and connectivity of each non-anchor node with neighbouring nodes within the particular site.

7. The dynamic self-organising network recording system according to claim 6 wherein the step to perform continuous collection of data until a new anchor node is assigned comprises the application to:

obtain data from the non-anchor nodes, the data includes performance parameters values from one or more of system, device, link, network, application level, and connectivity of each non-anchor node with neighbouring nodes within the particular site;

determine a score for each of the mobile nodes;

determine whether the score for the anchor node is below a pre-determined threshold; and

in response to determining the score for the anchor node is below a pre-determined threshold, assign a new anchor node.

8. The dynamic self-organising network recording system according to claim 7 wherein the step to determine a score for each of the mobile nodes comprises the application to:

assign a locality score, $Score_L$, to each mobile node based on the location of each of the mobile nodes within the boundary of the site with respect to a centroid location;

assign a connectivity score, $Score_C$, to each mobile node based on connectivity with neighbouring nodes;

assign a reliability score, $Score_R$, each mobile node based on the reliability determined which is a probability of any two nodes having an operative path connecting them;

determine the score for each mobile node with the following expression,

$Score_T = Score_L + Score_C + Score_R$); and

store $Score_T$ of each mobile node.

9. The dynamic self-organising network recording system according to claim 7 wherein the step to assign a new anchor node comprises the application to:

assign the mobile node with the highest $Score_T$ as the new anchor node;

notify the new anchor node to take over as the anchor node; and

transmit the data signature of the particular site and all data received to the new anchor node.

10. A dynamic self-organising network recording method for a particular site having a plurality of mobile nodes, the method comprising:

determining if an anchor node is available for the particular site;

in response to determining an anchor node is not available for the particular site, assigning the mobile node as the anchor node, performing a setup for the particular site in order to initiate collection of data to create a data signature of the particular site, and performing continuous collection of data until a new anchor node is assigned; and

in response to determining an anchor node is available for the particular site, responding according to request from the anchor node.

11. The dynamic self-organising network recording method according to claim 10 wherein the step of performing the setup for the particular site in order to initiate collection of data to create the data signature of the particular site comprises:

determining an operating environment; and

checking availability of cross layer Performance Reference Profiles (PRP) for the corresponding operating environment.

12. The dynamic self-organising network recording method according to claim 11 wherein the step of performing the setup for the particular site in order to initiate collection of data to create the data signature of the particular site further comprises:

in response to no cross layer PRP available, conducting a wireless site survey.

13. The dynamic self-organising network recording method according to claim 12 wherein the step of conducting a wireless site survey comprises:

creating a layout map of the particular site;

recording other mobile nodes in the particular site as non-anchor node;

creating a layout plan according to the particular site;

defining zones of each of the non-anchor nodes with respect to the anchor node location; and

scanning and collecting, from each of the non-anchor nodes, all performance parameters values from one or more of system, device, link, network, application level to create a data signature of the particular site.

14. The dynamic self-organising network recording method according to claim 13 wherein the step of creating the data signature of the particular site comprises:

determining statistical values for all performance parameters values obtained through wireless site survey in blocks of predetermined period for all zones.

15. The dynamic self-organising network recording method according to claim 10 wherein the step of performing continuous collection of data until a new anchor node is assigned comprises:

obtaining data from the non-anchor nodes, the data includes performance parameters values from one or more of system, device, link, network, application level, and connectivity of each non-anchor node with neighbouring nodes within the particular site.

16. The dynamic self-organising network recording method according to claim 15 wherein the step of performing continuous collection of data until a new anchor node is assigned comprises:

obtaining data from the non-anchor nodes, the data includes performance parameters values from one or more of system, device, link, network, application level, and connectivity of each non-anchor node with neighbouring nodes within the particular site;

determining a score for each of the mobile nodes;

determining whether the score for the anchor node is below a pre-determined threshold; and

in response to determining the score for the anchor node is below a pre-determined threshold, assigning a new anchor node.

17. The dynamic self-organising network recording method according to claim 16 wherein the step of determining a score for each of the nodes comprises:

assigning a locality score, $Score_L$, to each mobile node based on the location of each of the mobile nodes within the boundary of the site with respect to a centroid location;

assigning a connectivity score, $Score_C$, to each mobile node based on connectivity with neighbouring nodes;

assigning a reliability score, $Score_R$, each mobile node based on the reliability determined which is a probability of any two mobile nodes having an operative path connecting them;

determining the score for each mobile node with the following expression,

$Score_T = Score_L + Score_C + Score_R$); and

storing $Score_T$ of each mobile node.

18. The dynamic self-organising network recording method according to claim 16 wherein the step of assigning a new anchor node comprises:

assigning the mobile node with the highest $Score_T$ as the new anchor node;

notifying the new anchor node to take over as the anchor node; and

transmitting the data signature of the particular site and all data received to the new anchor node.