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Minimizing Redundant Route Nodes in USN by Integrating Spatially Weighted Parameters: Case Study for University Campus

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가중치가 부여된 공간변수에 의거하여 USN 루트노드 최소화 방안 -대학 캠퍼스를 사례로-

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Abstract : The present USN (Ubiquitous Sensor Networks) node deployment practices have many limitations in terms of positional connectivity. The aim of this research was to minimize a redundancy of USN route nodes, by integrating spatially weighted parameters such as visibility, proximity to cell center, road density, building density and cell overlapping ratio into a comprehensive GIS database. This spatially weighted approach made it possible to reduce the number of route nodes (11) required in the study site as compared to that of the grid network method (24). The field test for RSSI (Received Signal Strength Indicator) indicates that the spatially weighted deployment could comply with the quality assurance standard for node connectivity, and that reduced route nodes do not show a significant degree of signal fluctuation for different site conditions. This study demonstrated that the spatially weighted deployment can be used to minimize a redundancy of USN route nodes in a routine manner, and the quantitative evidence removing a redundancy of USN route nodes could be utilized as major tools to ensure the strong signal in the USN, that is frequently encountered in real applications.

Key Words : USN, redundant route nodes, epatially weighted parameters

요약 : 현재 유비쿼터스 센서 네트웍(USN: Ubiquitous Sensor Networks)의 노드를 배치하는 방식은 위치 적정성의 관점에서 많은 한계를 가지고 있다. 본 연구는 가시권 분석, 셀중심에 대한 인접성, 도로 밀도, 건물밀도, 셀중첩 비율을 GIS 데이터베이스로 구축하고 공간변수별 가중치에 의거하여 USN루트 노드 설치를 최소화하는 방안을 제시하였다. 기존의 전형적인 격자형 방식에 의거한 USN에서 24개의 루트노드가 필요하였지만 공간가중치에 의한 분석방법은 11개의 노드만으로 네트웍의 구성이 가능하였다. 11개의 노드만으로 구성된 USN에서 신호강도(RSSI: Received Signal Strength Indicator)는 다양한 지점에서 급격한 변동을 보이지 않고 노드의 연결성에 대한 성능평가 기준을 충족하였다. 공간가중치를 반영한 노드의 배치는 USN노드 배치에서 격자형방식이나 무작위로 설치하는 관행을 개선될 수 있는 계기가 되어 USN의 운영과정에서 신호강도를 확보할 수 있는 중요한 참고자료가 될 수 있을 것으로 사료된다.

주요어 : USN , 과대설치된 루트노드, 가중치가 부여된 공간변수

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1. Introduction

Wireless Personal Area Networks (PANs) and Local Area Network (LAN) are currently moving to the "anywhere and anytime" ubiquitous services. With the emergence of cheaper, smaller, faster, and smarter in situ sensors, the increasing availability of abundant ubiquitous computing devices, ubiquitous services have clearly become a technological trend (Steve *et al.*, 2005; Kim, 2008). Therefore, USN has attracted a great deal of research attention due to a wide range of potential applications (Fritsch *et al.*, 2001; Breunig and Baer, 2004; Casademont *et al.*, 2004; Jiang and Yao, 2006; Li, 2006; Liu and Karimi, 2006). USN may contain hundreds or thousands of nodes, and they may need to be deployed in remote, non-visible or dangerous environments, allowing users to extract information in ways that would not have been possible otherwise. One of the fundamental issues that arise naturally in the USN is node deployment. It is one of the most important factors in proper operation of the sensor networks and is considered a measure of service quality for a USN.

Due to the large variety of sensors and their applications, USN coverage is subject to a wide range of ground conditions. In order for the USN to be located at a spatially optimized site, it is important to understand the spatial parameters that are relevant to any USN. From a geomatics perspective, the location has been identified as the key for wireless sensor networks, and has become a major research focus in the field of sensor networks (Krzanowski and Raper, 1999; Dodd, 2001). In the process of node deployment, one has to look at every piece of a spatial parameter individually. Furthermore, one has to put them all together and look at the whole (or bigger) picture. Every node has its own place in every different situation and position. Concentrating on one point to the exclusion of all others, does not lead to a balanced point of view. However, the existing approaches for node deployment do not consider several distinctive features of geographical information: especially an integral attribute of spatial data, various ground conditions and application diversity. In most current designs, nodes are randomly or uniformly distributed based on a grid-like deployment topology because of its simplicity (Akyildiz *et al.*, 2005; Rui *et al.*, 2006, Akl and Sawnt, 2007).

One of the major disadvantages of traditional grid deployment is that it is costly, laborious and time consuming due to the large number of nodes required. Nevertheless, node redundancy and weak connectivity can be quite common, especially where the terrain features are not uniformly distributed in the field. The uniform deployments do not correspond to uniform connectivity owing to unpredictable propagation effects caused by artificial structures such as buildings. They do little address the overall impacts of such node deployments on the interconnections and collaborations between sensors and sensor networks. If a great number of nodes are to be deployed to cover an area-wide ground target, the cost disadvantage will apply to the whole coverage. USN node deployment represents a great potential application for GIS which is largely unfulfilled.

Simultaneously locating and configuring the best node site for a given land use or activity is a complex spatial planning problem. Site search problems that involve explicit spatial characteristics require spatial optimization approaches. GIS is an ideal technology capable of integrating, merging and analyzing multiple thematic layers simultaneously, to explore spatially optimized sites that are necessary when deploying many node stations in the USN. Until recently, the investigations of node redundancy by grid-based-deployment remained largely theoretical, because the non-spatial analysis technique had difficulty in assembling multi-spatial factors simultaneously. The multivariate spatial analysis compares multiple thematic layers at one time, and answers questions such as, "How much more important is one theme over the other". This relative importance among variables, related to USN node deployment had not been investigated in the context of a spatial multi-criteria framework. In node deployment, the multivariate spatial analysis is never used in conjunction with the weighting scheme. It is certain that more USN will be constructed in many places in the near future and it is also apparent from recent global trends that concern for economic and environmental impacts of such node deployment may be of world-wide importance.

There is, therefore, an imperative need to identify an appropriate practical technique for minimizing node redundancy, by differentiating relative importance among major controlling factors in USN node deployments. Consequently, the major research questions investigated in this study focused on evaluating the validity of the node deployment technique, within the GIS framework to minimize route node redundancy for a university campus, as an example of the USN target. This was in an effort to highlight inefficiency in regular node deployment, and to reveal a consensus on the minimum number of nodes required under a threshold level of connectivity to achieve the best possible ubiquitous service. This research was initially motivated by the requirement to provide USN managers with realistic 'hands-on' management of route node redundancy, without the problems associated with access to 'live' network, thus a simulation-based approach has been adopted. It offers USN managers insights into the processes by which the node redundancy is controlled by weighted spatial parameters. It is also designed to show evidence of how the simulated node deployment can be effective in their inter-node communications.

2. Theoretical background

There are two types of ubiquitous sensor networks, namely infrastructure networks and ad hoc networks. Infrastructure networks involve fixed and wired gateways. Typically these networks have a number of fixed base stations and mobile units that move within the network from one base station to another. Wireless local area networks are a classic example. In ad hoc networks the nodes are all mobile and maintain routes to neighboring nodes as the network changes. Sensor networks are a type of ad hoc networks.

Depending on the application, a node can be dedicated to one of three specific functions such as relaying, sensing or aggregation (sink). The data collected by sensor nodes are forwarded through the router nodes to more powerful sink nodes. Sensing nodes are identifiable through the address of the router node it is connected to. These sensor networks can be queried through a gateway (sink or base station) connected to the internet. A route node has one or more sensors attached that are connected to the physical world to monitor various properties.

Today' s highly competitive and advanced semiconductor industry makes route node' s computing processors faster and cheaper than ever, and could accommodate enormous amounts of distributed and heterogeneous sensing resources. So far, over 100 physical (light, pressure, humidity, etc.), chemical (gas, liquid, solid, etc.) and biological (DNA, protein, acoustics, etc.) properties can be sensed by using in situ sensing technology (Steve *et al.*, 2005). Most examples of actual USN deployments, where a number of sensing nodes are deployed in a network, have focused on the use of off-the-shelf physical transducers, and typically common environmental parameters such as temperature, humidity, light and atmospheric pressure are monitored. USNs based on these types of sensors have proved to be very useful for a range of different monitoring scenarios.

Network design for mobile communications is based on the cellular concept. It represents the theoretical area that will receive a signal transmitted from a base station located in its center. A mobile network is organised in a structure of cells. All mobile terminals in a cell communicate by a radio link with a fixed base station within the cell. The base station provides the access point to the network for users, allowing them to make and receive calls. In order to achieve deterministic coverage, a static network must be deployed according to a predefined shape.

In contrary to typical communication networks classical IP-based protocols cannot be applied to ubiquitous sensor networks and information moves hop by hop along a route from the point of production to the point of use. Each node has a radio that provides a set of communication links to nearby nodes. By exchanging information, nodes can discover their neighbors and perform a distributed algorithm to determine how to route data according to the application' s needs. If too few of the deployed nodes are used, the distance between neighboring nodes will be too great and the packet loss rate will increase; or the energy required to transmit the data over the longer distances will be prohibitive.

The received signal strength indicator (RSSI) in RF (Radio Frequency) communication indicates that nodes be able to communicate with each other in the established network infrastructure and predefined node locations. Received signal power between base stations and to subscribers needs to be calculated to determine the viability of the radio links (Sandrasegaran and Prag, 1999). RF coverage area in a given geographical region is defined to be locations where the signal strength exceeds the wireless system' s standard design level. It generally refers to the geographic area in which a remote station may effectively communicate with a base station without significant signal interruption or degradation.

The transmission loss and signal power can be predicted by a set of radio propagation loss modelling equations and link budget equations. The possible communication range from the base station can be estimated if the value of Received Signal Strength Indication (RSSI) is available. The free-space path loss (Ikegami, 1993; ITU-R Assembly, 1999) is the loss in signal strength of an electromagnetic wave that would result from a line-of-sight path through free space, with no obstacles nearby to cause reflection or diffraction. For typical radio applications, it is common to find measures in units of GHz and in meter, in which case the FSPL (free-space path loss) equation becomes like this;

$FSPL\ [dBm] = 32.44 + 20\log f + 20\log D$, f: frequency (GHz), D: a line-of-sight distance

A link budget is the accounting of all of the losses from the transmitter, through the medium (e.g. free space) to the receiver in a telecommunication system. A simple link budget equation looks like this:

Received Power(dBm)=Transmitted Power(dBm) -FSPL(dBm)

In real scenarios, the received signal strength is not only dependent on the distance between the transmitter and the receiver, but also on the environment. If line of sight (LOS) communication is blocked by spatial parameters such as hills or tall buildings, coverage estimation based on the free-space model is not relevant because of its over-simplifying assumptions. Mathematical models, such as the Cost 231/HATA method, are conventionally used to predict whether a site located at in urban areas is serviceable by a fixed wireless system.

3. Data and method

This study was conducted on the campus of Kyungpook National University (KNU), which is located in Daegu metropolitan city of South Korea (Figure 1). It is situated in the south-eastern part of the Korean Peninsula, at latitude 35.53°N, and between longitudes 128.36°E and 128.37°E. Experiments for such node deployment require a suite of networks with different scales, ranging from laboratory-scale networks, comprised of a handful of nodes, to operational networks comprising hundreds of nodes.

The KNU site has several advantages that make it an appropriate choice for such a small-scale ubiquitous sensor network, covering approximately 782,000m^2 (Figure 1). It is an ideal site to implement small-scale USN that consist of a relatively small number of sensors controlled by one central device, that do not require complex multi-hop routing, data aggregation and other protocols characteristic for large sensor networks. Its elevation ranges from approximately 35-62m, and such relatively distinctive elevation ranges within the small-scale USN, make the visible region of the surface easily observed from the designated node points. Various requirements for the development of small-scale sensor networks have been already satisfied, such as artificial structures and a confined boundary to establish

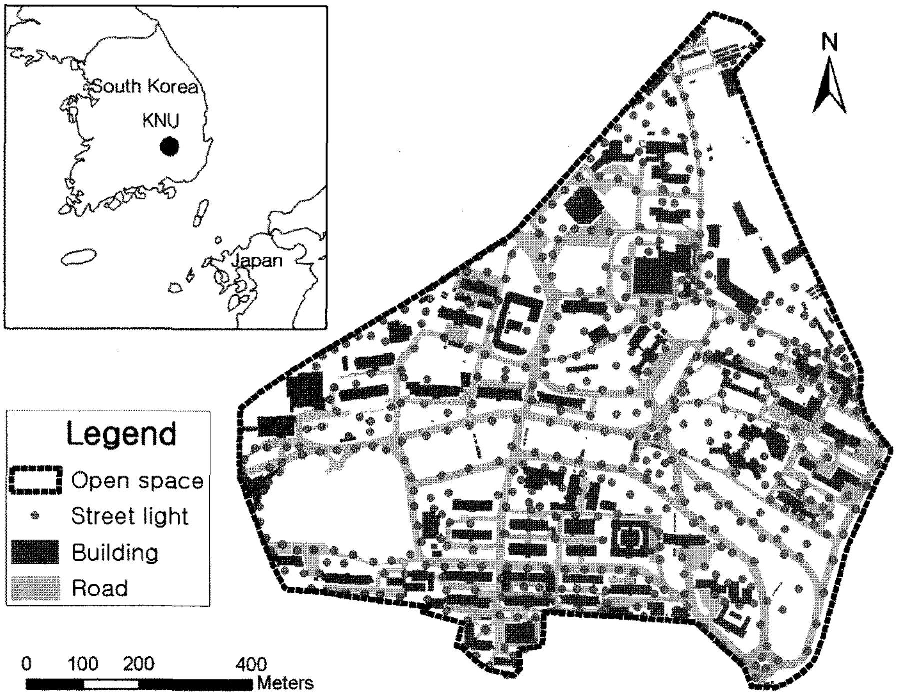

Figure 1. Location map of the study area (KNU: Kyungpook National University).

hardware and software platforms.

It was necessary to focus on a representative node among three different nodes (sink, route, sensor), in order to design an experimental procedure in a straightforward manner. The main focus has been given to demonstrating the effectiveness of the route node deployment. Any route node deployment project has common connectivity problems, which will depend on site characteristics such as topography, building density, building type, and road density, etc. In general, a route node may be used in different environments supporting diverse applications, although some applications may need to be focused on different sensory data, and therefore impose different requirements in terms of quality of service and reliability. Most applications usually do not have different requirements in data delivery and communication with respect to accuracy and energy consumption, since a route node is applied in a universal sense, and does not have to be tied to any particular application scheme (Camp and Tsang, 2000; Park *et al.*, 2007). Although data reading and reporting can be generated from these sensors at different rates, subject to diverse quality of service constraints, they can be covered by standard routing models for multiple data. Even inclusion of a heterogeneous set of sensors does not raise specific technical issue related to data routing (Ando 2003; Ogata 2004; Park 2005). It is believed that the results of this study are not only applicable to specific route nodes in a university campus, but also to general cases, since they deal with common problems in the route node deployment.

Although the physical placement of a node determines its connectivity, it is subject to complex, interacting influences such as battery life, routing protocols, antenna orientation, and mobility. Several of these notably compete for favorable landscape and micro-site variability. It would clearly be impossible to accommodate the behavior of every subjective variable involved in the node site location. This method is extremely subjective, since the node location exercise has to be run under vast numbers of combinations of rules, its approach is conceptually non-spatial. In order for this research to be focused, it was necessary to investigate criteria that are locally relevant and measurable in a spatial framework.

University campuses are very distinct

Table 1. Thematic layers utilized in the process of spatial analysis.

Name of thematic map	Type of data category	Role as spatial parameters
Building	Polygon	DTM (Digital Terrain Model) generation Building density calculation
Road	Polyline Polygon	Calculate proximity to road Road density calculation
Center line of the road	Polyline	Calculate road width
University Boundary	Polyline	Define university boundary
Contour	Polyline	DTM generation
Height point	Point	DTM generation
Traffic light	Point	Identify energy source
Electricity pole	Point	Identify energy source

communities. They can be regarded as 'small cities' due to their large building size, their own streets, squares and open spaces and are usually self-contained urban areas where classrooms, offices, apartments, student centers, child care facilities, performance halls, art galleries, gymnasiums, swimming pools, sports arenas and shopping places are all in close proximity (Alshuwaikhat and Abubakar, 2008). In this regard, most university campuses are struggling with the same radio propagation environment as most urban areas. The main focus has been given to demonstrating the influence of the variables used frequently in a radio propagation model (e.g. Cost 231) developed for urban areas such as the visibility, road density, building density and proximity to road etc., as the most important factors controlling the spatial location of the route node (Table 1). A digital topographic map (1:1000) obtained from the university (produced in 2002 from aerial photography taken during the same year) was used to extract the required thematic maps, such as contours, height point, road network, buildings and university boundaries. The base map was produced by the local government in accordance with the guideline suggested by National Geographical Information System Committee and facility data such as traffic light, electricity pole, and communication line were added by the university.

The ArcGIS package was used in the data analysis procedure since it has a wide variety of applications due to its already vast user base. The need for a new tool, or replacing an existing one, does not make much sense since the ArcGIS platform satisfies most of the functional requirements for this project such as spatial analysis and 3D analysis, although other systems would support such an application as well. It was also considered that using common software will facilitate the expanded use of this research output since it takes a considerable amount of time to learn and use new software effectively. It was impractical to use a variety of GIS software with this project. GPS (Global Positioning System) was used to read and integrate database tables for the field test site, directly or by means of SQL-queries. For a node site selected by spatial analysis, the field RSSI test was undertaken using a Cratto CRM-ZR110 (Table 2).

4. Spatially weighted analysis

The analysis requires a two-stage area-selection activity, with a view to identifying prospective candidate node locations for further exploration. In the first stage (Figure 2), propagation distance of the nodes was estimated using the radio propagation model. Once the equidistant

Table 2. Data and equipment used for the study.

Software and hardware	Specifications	
Digital topographic map	1:1000 scale	Extracting spatial parameters
GPS receiver	Axiom GPS	Ground truth point location
ArcGIS 9.1/ AutoCAD Map 2000	ArcMap, ArcCatalog, ArcScene, ArcToolBox	Spatial analysis/ thematic map editing
USN route node	Cratto CRM-ZR110 RF ChipSet : CC2420(CHIPCON Inc) Antenna Height: 5m	RSSI measurements

hexagonal cells from neighboring sites had been created, the entire study area was investigated to reduce the number of nodes using a class of spatial search tools such as visibility, proximity calculation etc. In the second stage of spatial analysis, promising node locations within the cells are explored in greater detail (lower right of Figure 2). The focus of spatial analysis is scoring each candidate according to its ability to support given spatially weighted parameters. A significant benefit of adopting a cell approach is that it serves to spatially decompose the entire site search problem into a set of smaller, local cell problems.

The Chipcon chipset used in this research (Table 2) can report an RSSI value of 0 to 255 for RF energy. The RSSI compliance standards are between -85 and -94 (Chipcon Inc, 2004) under the 10mW power of transmission value as proposed by IEEE Standard 802.15.4^{TM}-2003 (IEEE, 2003). The propagation distance of 200m was derived analytically from the free-space loss value of 92.8 since the received signal power of -82.08 dBm could comply with the RSSI compliance standards of the RF ChipSet (between -85 and -94).

NOTE: Estimation of number of route nodes required for grid deployment

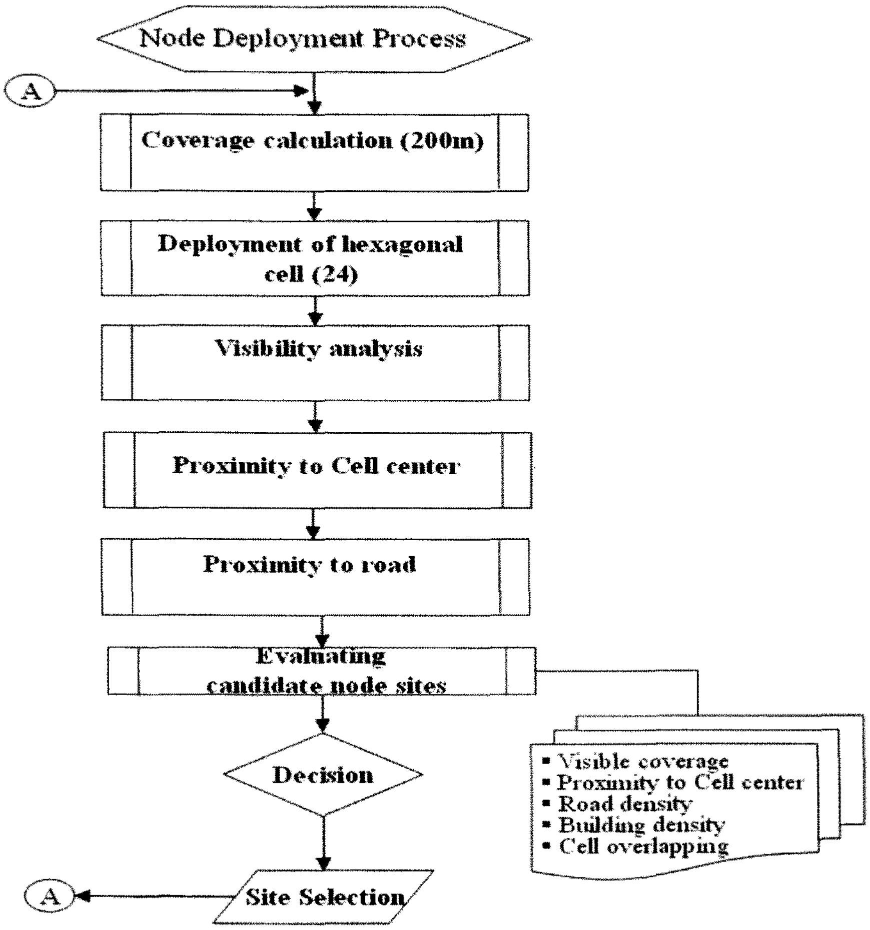

Figure 2. Node deployment procedure integrating spatially weighted parameters.

FSPL 92.08 [dB]=32.44+20log 2.4Ghz+20log 200m, f: frequency (Ghz), D: distance
Received Power -82.08(dBm)=Transmitted Power 10(dBm)-FSPL 92.08(dBm)
Number of route nodes required for grid deployment=200*200/782,000=19.55
Although the number of nodes required is estimated at 19.55, 24 nodes were required to cover the polygon shape of the study area as shown in Figure 4a.

The Voronoi diagram (ESRI (Environmental System Research Institute), 2006) was used to produce a regular hexagonal cell with edges that are equidistant (200m) from neighboring sites as shown in Figure 4b. All route nodes located at the center of the cell are assumed to be homogeneous, i.e., having equal capacity in terms of communication range (200m) and power (Table 3).

A visibility algorithm in GIS was introduced to

Table 3. Received signal power in free space and number of route nodes required.

Transmitted Power	Frequency (Ghz)	RSSI (dBm) Compliance standards	Free space loss (dBm)	The received power (dBm)	Coverage (m)	Size of study area (m^2)	Number of route nodes required for grid deployment
10mW (dBm)	2.4	between -85 and -94	92.08	-82.08	200*200	782,000	24

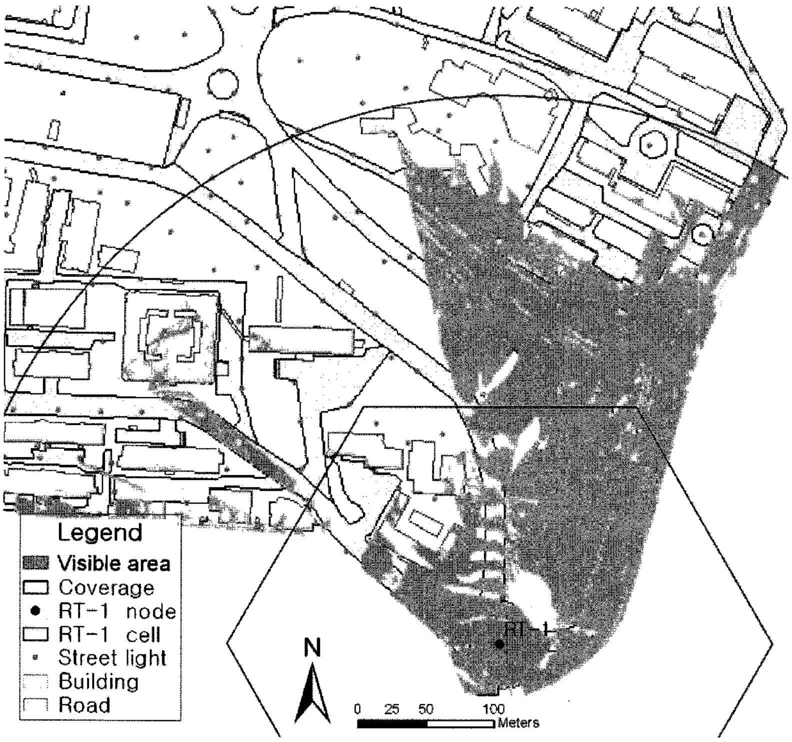

Figure 3. Visibility analysis applied to the RT-1 node.

Note: This shows that a given sensor's view of the environment is limited both in range and in distance due to artificial structures.

ensure line-of-sight in the network area (Figure 3). It was possible to identify the given sensor's view of the environment throughout the entire network. A key feature of such networks is that their nodes are untethered and unattended. Consequently, they have limited and non-replenishable energy resources. In order to maintain the battery lives of the route nodes in a given visible region, each zone needs energy sources such as street lights or buildings. Artificial structures located within 50m of the cell center were identified using spatial buffer techniques. Route nodes often cover overlapping areas, and nodes often gather overlapping pieces of sensor data. When two nodes (A and B) gather such overlapping data and then flood the data to their common neighbor (C), the overlapping geographic nodes waste energy, sending two copies of data to the same node. Since the overlapping shows indicative information for healthy signals, routing nodes overlapping geographic areas were removed to constrict the data dissemination to the relevant region, and to reduce routing control overhead. Such an approach can ensure a system-wide connectivity due to the centralized location of nodes at the cell, with less overlapping of connections to a ubiquitous network.

Once physical placement of the candidate cells for the entire study was determined, the multivariate spatial analysis was introduced to identify whatever connectivity is present among

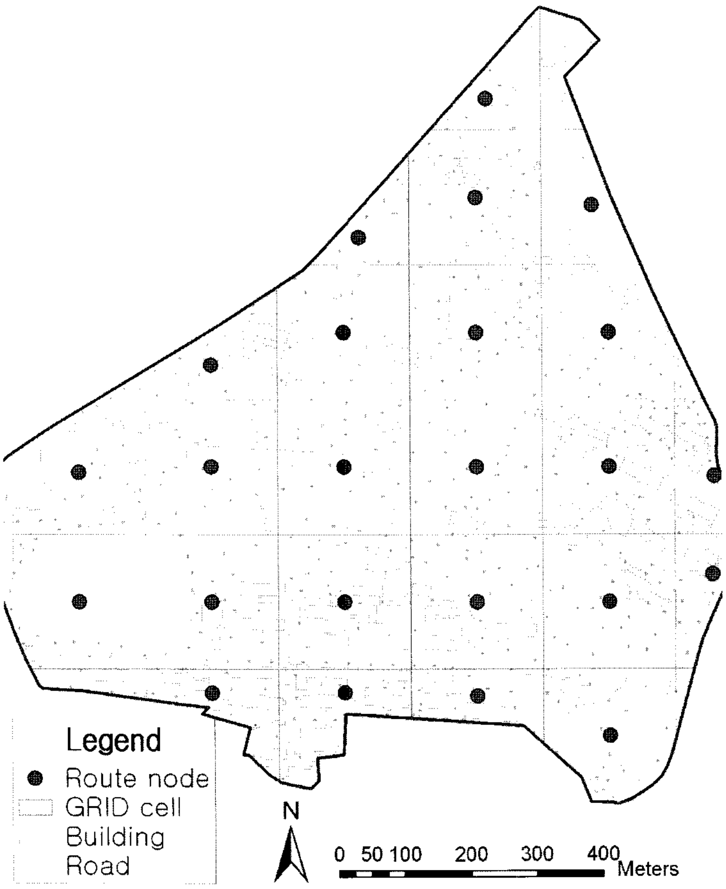

Figure 4a. The node array (24) deployed by a regular grid (based on distance).

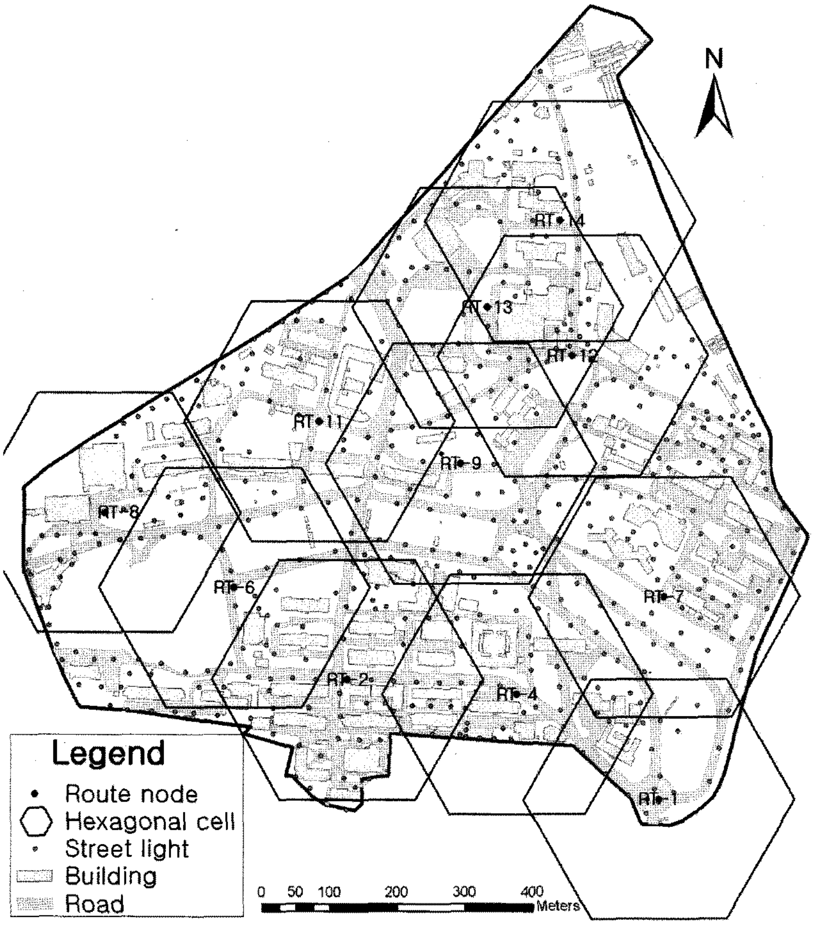

Figure 4b. The node array (11) reduced by network-wide spatial analysis.

the node candidates within the cell (Figure 5), by integrating spatially weighted parameters such as road density, building density and proximity to cell center as shown in Table 3 and lower right of Figure 2. However, there is no fixed or standard value of weight for node deployment-related factors. In order to minimize the inherent subjectivity of the weighting process, the relative significance of each variable was quantified by applying the Analytical Hierarchy Process (AHP) developed by Saaty (1980).

The AHP is a theory of measurement for dealing with quantifiable and intangible criteria and gained wide application in site selection and suitability analysis (Shim, 1989). In the AHP method, pairwise comparisons form the backbone of the methodology. The pairwise comparison approach coupled with a ratio scaling method is frequently used to uncover the relative importance among all decision criteria, in multiple attribute decision-making environments (Saaty, 1980; Sui, 1992; Banai, 1993; Weerakoon, 2002). This decreases the subjectivity of the study and is an advantage of the AHP method. With the comparative judgments, users are required to set up a comparison matrix at each hierarchy by comparing pairs of criteria or subcriteria. A scale of values ranging from 1 (indifference) to 9

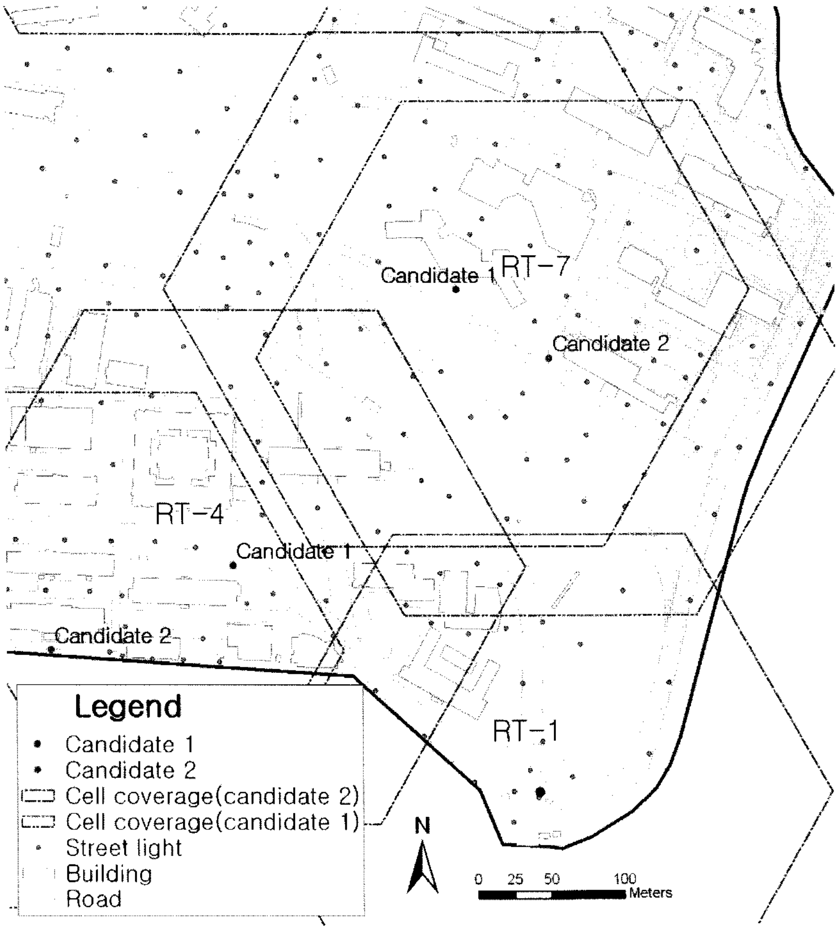

Figure 5. Node candidates within an individual cell to be selected based on weighting score.

Table 4. Relative importance among spatial parameters.

	Visible coverage	Proximity to cell center	Road density	Cell overlapping*	Building density**	Relative importance
Visible coverage	0.544	0.620	0.556	0.469	0.435	0.525
Proximity to	0.140	0.159	0.173	0.214	0.282	0.194
Road density	0.124	0.116	0.127	0.137	0.141	0.129
Cell overlapping	0.097	0.062	0.077	0.084	0.066	0.077
Building density	0.094	0.043	0.068	0.096	0.076	0.075
Total						1

* cell overlapping ratio = overlapping area / cell coverage (103,923m^2)

** building density = built area / cell coverage (103,923m^2)

(extreme preference) are used for expressing users preference. At the end, synthesis of priorities is conducted to calculate a composite weight for each alternative based on preferences derived from the comparison matrix (Laia *et al.*, 1999).

Nine preference degrees were scaled for experts to qualitatively judge the five factors as presented in Table 4. The expert judgments were essential, since it was hard to obtain reasonable opinions from non-experts, about the importance of factors related to USN node deployment standards. Seven experts related to USN and RF (Radio Frequency) were interviewed, to reach a consensus in setting a weighting scheme. Table 4 shows the resulting relative importance weights among spatial parameters in the hierarchy structure. The consistency ratio (CR) is designed in such a way that if CR<0.10, the ratio indicates a reasonable level of consistency in the pairwise comparisons; if CR≥0.10, the values of the ratio are indicative of inconsistent judgments. The CR was calculated in order to determine whether the pairwise comparisons were consistent or not. The consistence ratio from AHP analysis was 0.018, which does not exceed the threshold of 0.10 (Weerakoon, 2002). It is frequently noted that the strongest signal of an electromagnetic wave is

Table 5. Route node candidates within each cell and their weighted scores.

Candidates (C)		Visible coverage	Road density	Proximity to cell center	Building density	Cell overlapping	Total
RT-1	1.00	1.00	1.00	1.000	1.000	1.000	
RT-2	C 1	0.18	0.31	0.31	0.348	0.370	0.252
	C 2	0.26	0.33	0.34	0.330	0.332	0.296
	C 3	0.55	0.36	0.35	0.322	0.299	0.453
RT-4	C 1	0.76	0.52	0.59	0.508	0.483	0.657
	C 2	0.24	0.48	0.41	0.492	0.517	0.343
RT-6	C 1	0.31	0.37	0.36	0.328	0.282	0.325
	C 2	0.33	0.30	0.32	0.336	0.345	0.326
	C 3	0.36	0.32	0.32	0.336	0.373	0.348
RT-7	C 1	0.49	0.51	0.52	0.504	0.446	0.495
	C 2	0.51	0.49	0.48	0.496	0.554	0.505
RT-8	C 1	0.40	0.58	0.36	0.325	0.331	0.404
	C 2	0.34	0.24	0.32	0.333	0.301	0.322
	C 3	0.25	0.19	0.32	0.342	0.368	0.274
RT-9	C 1	0.64	0.51	0.51	0.511	0.555	0.582
	C 2	0.36	0.49	0.49	0.489	0.445	0.418
RT-11	C 1	0.52	0.52	0.49	0.499	0.469	0.507
	C 2	0.48	0.48	0.51	0.501	0.531	0.493
RT-12	C 1	0.11	0.34	0.33	0.338	0.558	0.235
	C 2	0.41	0.35	0.37	0.338	0.144	0.370
	C 3	0.48	0.31	0.30	0.324	0.298	0.396
RT-13	C 1	0.16	0.23	0.16	0.331	0.126	0.181
	C 2	0.40	0.38	0.44	0.334	0.399	0.400
	C 3	0.44	0.39	0.40	0.335	0.474	0.419
RT-14	C 1	0.52	0.46	0.46	0.485	0.445	0.493
	C 2	0.48	0.54	0.54	0.515	0.555	0.507

Note: Total Score = visible coverage × 0.525+road density × 0.129+proximity to cell center × 0.194 +building density × 0.075+cell overlapping rate × 0.077

Enbolded candidate in total score was finally selected as route node location.

formed by a line-of-sight path through free space, with no obstacles nearby to cause reflection or diffraction (Juan *et al.*, 1999). In this regard, a strong preference for visibility over all other criteria is indicated as the most important factor in the node site selection and evaluation process (Table 4).

Multivariate spatial analysis combines individual thematic layer's weighting into a more compact form (Table 5). Total weighting gathered from multiple spatial data has produced reliable evidence for locating the nodes in an area of interest (Figure 5). The visible coverage did make a significant contribution to explaining the variance in total weighting. By contrast, the ratio of cell overlapping and the ratio of building density were the least significant variable in the weighting scheme (Table 5). A variety of spatially weighted parameters can be controlled, in order to adapt to the current network conditions accommodating expert opinion for all the nodes.

The sampling density for RSSI measurement in the network was about one sample per 40m distance and 30° (twelve samples per circle) from the cell center. It was expected that the dense sampling interval could consistently recognize the RSSI fluctuations pattern, since individual RSSI variations among the cells could be detected within a 40m communication range of the node. The number of samples ranging 25 to 50 was sufficient to extract reliable information relating to the existing state of the node operation in question, as substantial evidence of the node deployment by the GIS.

5. Result and discussion

The cell-based spatial analysis map disclosed evidence that less-connective cells are mainly under the influence of visibility, as a derivative of the integrated spatial parameters such as building density, road density and elevation, as shown in Figure 4a-b. There are huge differences in visibility degree among cells, and clear regional patterns can be observed. Geographically, the visibility in the south-western section of the study area was almost twice as high as that occurring in the rest of the region. Therefore, the total number of nodes required in the entire network was 24, when they were based on the common belief that node connectivity is always directly dependant on distance (Akyildiz *et al.*, 2005; Akl and Sawant, 2007). The spatial analysis discovered cells showing weak visibility and suggests future deployment or reconfiguration schemes required to improve the overall quality of service. The spatially weighted analysis allowed strategically less-connective areas to be focused, and the cells requiring nodes can be drastically reduced (11), ensuring strong connectivity to the whole network.

Summary data for assessing the level of consistency among the USN nodes are presented in Table 5. The spatially weighted deployment showed strong connectivity, yielding RSSI values ranging from -86.00 to -53.82 between nodes owing to accommodation of unpredictable propagation effects, when nodes are close to artificial structures such as buildings. The data does not show a significant degree of variability (average standard deviation: 9.64) for different site conditions, satisfying the RSSI compliance standards (between -85 and -94). The node deployment accommodating spatially weighted parameters precludes them from being completely isolated from each other. The relationship between the RSSI values and the building density is distinct, and a clear spatial pattern could be observed. For instance, the RSSI decreased as the building density increased (e.g. RT 2), while a much higher RSSI was observed in the scattered building area (RT 1, Table 6).

Table 6. Field measurement for RSSI.

(Unit: dBm)

Route node	Number of samples	Mean	Maximum	Minimum	Standard deviation
RT-1	31	-67	-52	-84	10
RT-2	25	-74	-62	-84	7
RT-4	25	-72	-49	-89	11
RT-6	50	-71	-51	-87	10
RT-7	44	-71	-45	-88	11
RT-8	45	-73	-53	-89	10
RT-9	42	-72	-56	-85	10
RT-11	36	-71	-54	-85	9
RT-12	39	-71	-57	-85	8
RT-13	31	-72	-57	-85	10
RT-14	29	-73	-56	-85	10
Total	397	-787	-592	-946	106
Mean	36.09	-71.54	-53.82	-86.00	9.64

Various algorithms and methods have been developed to identify wireless access points based on signal measurements (Dodd, 2001). Several studies have noted that radio networks tend to be dependent on spatial parameters (Rose, 2001). Several of these range from fairly simple triangulation to more complex hierarchical Bayesian sensor models (Letchner *et al.*, 2005). In most cases, location information was used to calculate the distance between two particular radio stations, so that signal strength could be estimated. The results of this study extended previous findings, specifically focused on the associations with the most influential spatial variables. Yu *et al.* (2001) suggests a systematic method to deploy a USN based on location information; however, one of the major shortcomings of their research is the absence of incorporating multivariate analysis based on weights for spatial parameters as proposed in a radio propagation model. It is noted that none of the prior studies mentioned above are specific to minimizing redundant route nodes with spatially weighted area-wide parameters. Perhaps, the most related works to this study are the networking attempts based on Delaunay triangulations (Megerian *et al.*, 2005). The sensor field cannot be expected to be deployed in a regular fashion. More importantly, regular distance based deployment cannot be expected to correspond to consistent signal strength, owing to unpredictable RF propagation effects.

To the best of our knowledge, this paper is the first work to calculate the optimized number of route node stations by strategically selecting the placement using analysis of multi-spatial parameters required in sensor networks. This study has demonstrated that a spatially weighted analysis can be utilized for resolving node redundancy, by overcoming serious subjective judgment suffered from lack of multi-thematic cartographic representation. The study presented here is, to our knowledge, the first one addressing explicitly, the relative importance of spatial variables in the process of specific arrangement of the individual node point. Preference weights measured for different routing requirements can vary significantly across individuals, and across groups these individuals represent. Nevertheless, the resulting signal strength showed that spatially weighted criteria derived from AHP could provide an equitable and efficient means for removing route node redundancy by incorporating expert's preferences.

This paper discusses the route node deployment for infrastructure networks which is deterministic, the sensors are manually placed and data is routed through pre-determined paths. However, in an ad hoc network, the nodes are scattered randomly. Although this research deals with infrastructure networks, it is desirable and applicable in the domain of ad hoc networks, because these networks have node redundancy as well and spatially optimized clustering becomes necessary to allow connectivity and enable energy efficient network operation. While the paper discuses the deployment of new nodes for infrastructure networks, these routing protocols can be integrated quite easily into where the nodes already exist and connecting them properly is the underlying task. The result of study could offer helpful insights in terms of a node rearrangement since the most likely and the worst-case site conditions can be identified by the spatially weighted parameters. This could be used as a guideline to identify the potential locations for node replacement and alternatives for recovery.

The node minimization technique developed in this study are general in purpose and do not consider the specific application workloads. In the near future, the availability of micro-sensors and low-power wireless communications will soon enable the deployment of densely distributed networks for a wide range of applications. The empirical choice of several connectivity threshold values for a variety of application is required to tune up the spatial parameters every time the experimental site condition changes. The methodology for redundant node minimization is based on a prior assumption that node connectivity retains the representation of the underlying background terrain surface pattern. The spatial dimensions of node site condition vary according to the way different societies construct different shared architectural spaces. Whereas this study effectively reduce redundant nodes based on spatially weighted parameters, further refinements need to include more detailed descriptions of the terrain and more accurate modeling of wave propagation based on the specific applications to produce more application oriented node locations. Therefore, the node minimization technique derived in this study will provide a standardized form as a basis for comparison against which the infrastructure and geographical differences among the variety of site condition differently behave this way.

6. Conclusion

The convergence between GIS and USN is not very popular currently however, popularity for it is set to rise markedly in the very near future. The USN node deployment linked to spatially weighted analysis, breaks down the usual concept of grid-based deployment established as a typical technique so far, and will help inform the evaluation of USN node locating strategies. This is one of the few studies that has looked at the relative importance of the differences, in spatial variables among node stations, and is the first to formalize a multi-thematic map integration approach for USN, with area-wide empirical evidence. The spatially weighted deployment results in much fewer node stations, as compared to the uniform deployment. Furthermore, it shows strong connectivity, ensuring small inter-node variation in the area-wide network. The two basic problems of node deployment--where to place nodes and how many nodes to place in the domain were solved via spatially weighted analysis.

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