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OPTIMAL SPATIAL PATTERN FOR WIRELESS SENSOR NETWORK BASED ON ENERGY MINIMIZATION IN INTELLIGENT TRANSPORTATION SYSTEMS

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ABSTRACT
Wireless Sensor Networks are proposed to improve vehicle safety to avoid collisions in congested junctions and to enhance the capability of warning systems in the event of an emergency. The critical challenge in sensor networks is the extended temporal operation of the individual sensor node using a typically limited battery power supply. The sensor node consumes power due to sensing, signal processing, embedded computing and connectivity. In this paper the spatial arrangement of the sensor nodes in a typical traffic junction will be determined. The emplacement of sensor nodes will be designed with the constraints of energy minimization and coverage area maximization. The sensor node placement techniques in WSN have been analyzed and addressed to increase the lifetime, area coverage maximization, indirect cost benefits due to reduced number of deployment of sensors due to optimal placement.

Keywords: intelligent transportation systems, wireless sensor networks (WSN), sensor placement, coverage-area maximization.

1. INTRODUCTION
The principal reason for traffic congestion in India is that the road space and infrastructure have not improved on par with the traffic [1]. Intelligent transportation systems (ITS) offer promising solutions to mitigate traffic congestion problems thereby avoiding vehicle collisions and improving vehicle safety. ITS program for India requires the development of low-cost solutions for road-wide data collection.

Currently most intelligent transportation systems (ITS) deploy expensive sensors which offer only limited functionality [2]. A recent trend consists of using Wireless Sensor Networks (WSN) for such applications as it reduces the required investment and enables the development of applications that contribute to improve driving safety and traffic efficiency. Wireless sensor networks consist of a large number of densely deployed sensor nodes using multi-hop communication to pass data through the network to a main location [3]. The main aspect of wireless sensor network that make the implementation of applications challenging is the limited power supply available to each wireless node.

In order to conserve the available power and prolong the life of the network, most of the research on wireless sensor networks has focused on reducing the end to end latency of the information delivered through the network and design optimization of the communication protocol stack [4].

However, careful node placement can be a very effective strategy for limiting the power consumed in each node. Deterministic placement of sensor nodes may work out well in case of traffic control applications as the context of this optimization strategy is mainly static due to the fixed topography of the traffic junction monitored.

This paper deals with the study of node placement in reducing energy consumption of wireless sensor networks deployed in typical traffic junctions. The study provides insights regarding the optimal spatial pattern of wireless sensor network for traffic junction based on energy minimization. The sensor nodes shall be circularly placed ensuring coverage of the monitored area. Performance metrics such as energy consumption and data latency shall be evaluated in comparison to the random sensor deployment.

The paper is organized as follows. The section 1 explains the energy consumption in WSN and model that has been used for the study. Section 2 discusses sensors in traffic monitoring and traffic estimation techniques. Section 3 describes sensor node deployment strategies. Section 4 optimal spatial pattern explains - node placement algorithm, the proposed algorithm, and stimulation. Section 5, finally drawn the results and conclusions from various node placement strategies for ITS applications and increased the scope of further research direction.

1.1. Energy consumption in WSN
A wireless sensor network consists of sensor nodes. Each sensor node is made up of four basic components namely: (a) a sensing unit, (b) a processing unit, (c) a transceiver unit and (d) a power unit [3]. Each sensor node uses energy for carrying out the main functions such as data acquisition, communication and data processing. Computation of the energy expended per node is an important factor to be considered when designing a wireless sensor network. Specifically the energy consumed in a sensor node due to data communication should be considered to find an optimal node placement such that the lifetime of the sensor network can be maximized with a given total number of nodes.

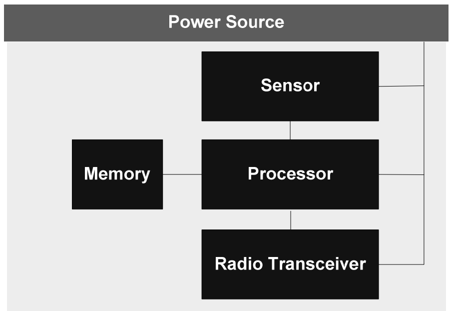

Figure-1. Schematic of a WSN node.

1.1.1. Energy consumption model

Clustering is a process of grouping nodes using an algorithm to perform certain tasks effectively as per the requirements. Clustering can also be used to divide the topology into sub-regions based on certain criteria e.g. whole area should be covered, minimum energy consumption, maximum lifetime etc. [18].

1.1.2. Radio model

For the radio hardware, the transmitter dissipates energy to run the transmitter radio electronics and power amplifier, and the receiver dissipates energy to run the receive radio electronics [17]. For the scenarios described in this paper, both the free space (d2 power loss) and the multi path fading (d4 power loss) channel models were used depending on the distance between the transmitter and receiver. If the distance is less than a threshold, the free space (fs) model is used; otherwise, the multipath (mp) model is used.

In the radio model of T amplifier, we use an alpha=2 for free space and alpha=4 for multipath model. Thus if a node transmits L number of bits, the energy used in transmission will be ETX (L,d)=Eelec.L+Eamp (L,d)

1.1.3. Path loss model

Path loss (or path attenuation) is the reduction in power density (attenuation) of an electromagnetic wave as it propagates through space [19]. Path loss is a major component in the analysis and design of the link budget of a telecommunication system. This term is commonly used in wireless communications and signal propagation. Path loss may be due to many effects, such as free-space loss, refraction, diffraction, reflection, aperture-medium coupling loss, and absorption. Path loss is also influenced by terrain contours, environment (urban or rural, vegetation and foliage), propagation medium (dry or moist air), the distance between the transmitter and the receiver, and the height and location of antennas.

2. SENSORS IN TRAFFIC MONITORING

2.1. Magnetic loops

Magnetic loop is a technology that has been used for vehicle detection and traffic control for the past few decades. These devices are installed inside each traffic lane and act as counters, counting vehicle passing over them. Some variants of the magnetic loop have been used to classify vehicles as well [5]. The loop is a continuous run of wire which is buried inside a traffic lane. The ends of the loop wire are connected through a loop extension cable to the vehicle detector. The detector powers the loop causing a magnetic field in the loop area. The magnetic flux linked with the loop changes whenever a metal object, such as a vehicle, moves over the loop. The detection scheme of loops is based on this principle. The change in flux is sensed by the detector which forces a normally open relay to close. The relay remains closed until the vehicle leaves the loop.

Inductive loops require extensive care during installation or repair. Troubleshooting problems in magnetic loops require costly test equipment or diagnostic software. The inductive loop requires continuous power supply to function. Hence, it is quite evident that magnetic loops being intrusive, expensive to install and maintain do not fulfill our requirements. Also these loops will only be useful in presence of laned traffic.

2.2. Camera based systems

Camera based systems are able to detect, count and classify vehicles. These systems use video image processors to identify vehicles and their traffic flow parameters by analyzing imagery supplied by video cameras. Images supplied by cameras are digitized and then series of image processing algorithms are applied on them. Information about vehicle passage, presence, speed can be extracted by using various image processing techniques. Though camera based systems are more accurate than loop based systems and do not require lane discipline they have several disadvantages. Their performance is unsatisfactory in foggy conditions of poor visibility. Other environmental conditions such as light reflected from wet pavements and shadows affect the performance of Video image processors. Large vehicles can obscure smaller vehicles. Camera based systems are expensive to install and maintain as they require quite a lot of dedicated hardware and software. Chances of theft are also higher for such systems.

2.3. Microwave RADAR

Microwave radars use specially allocated radio frequency for detecting vehicles. In the U.S. 10.525 GHz is allocated for this purpose. There are two types of microwave radar detectors. The first type of microwave radar uses the Doppler principle to detect vehicles. According to the Doppler principle the difference in frequency between the transmitted and received signals is proportional to the speed of the vehicle. So this type of microwave radar first transmits electromagnetic energy at a constant frequency. If the detector senses any shift in the received frequency it deduces that vehicle has passed. On major problem with this type of microwave radar is that it cannot detect stationary vehicles. The second type of microwave radar detector transmits a frequency-modulated continuous wave that varies the transmitted frequency continuously with time. This enables the system to measure the range of the vehicle from the detector. Hence,

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this type of microwave radar can detect stationary vehicles as well. Speed of the vehicle can be calculated by measuring the time taken by a vehicle to move between two internal markers separated by a known distance. However, even these microwave radar systems have problems like over estimating speed and occupancy values.

2.4. Laser based systems

Laser based systems can be used to for counting, classifying and measuring speed of vehicles. Laser based systems offer reliability and durability. Unlike systems based on magnetic loops the installation of these systems does not need any civil engineering work to be done on the floor of the road. Laser detectors, however, need to be installed on a overhead position. Thus, an overhead structure is needed for these systems. Also these systems assume structured traffic on the road which is not the case in India [7].

2.5. Infrared detectors

Passive infrared detectors do not transmit energy but instead use an energy sensitive photon detector located at the optical focal plane to measure the infrared energy emitted by objects in the detector's field of view. Thus, when a vehicle enters the detection region of the device, it produces a change in energy which is sensed by the photon detector [8].This system can only detect vehicle passage or presence. It cannot provide any information regarding speed of the vehicle. Change in weather conditions such as fog, rain or snow results in performance degradation of these systems.

2.6. Ultrasonic detectors

Ultrasonic sensors use sound waves (above the audible range) to determine the presence or distance of an object. Ultrasonic detectors transmit sound at 25 KHz to 50 Khz. A part of the transmitted energy is reflected back from the road or the vehicle to the receiver. By measuring the time taken for the sound echo to return the distance of an object can be found [9]. The ultrasonic Doppler detector that also measures vehicle speed are much more expensive than the presence detector. This technology is expensive and is sensitive to noise and environmental conditions.

Ultrasonic, infrared, microwave radar detectors and laser based system all assume some form of lane discipline or structured traffic. They are generally suited for expressway and toll booths. But under our constraints they will not suite. Laser based and radar systems are non-intrusive they do require setting up of additional infrastructure in form of overhead mounting points. These systems along with camera based system lack the flexibility of large scale deployment [10]. All these systems are fairly expensive as they are mostly based on propriety technology and specialized equipment.

2.7. Anisotropic Magneto-Resistive (AMR) magnetic sensors

AMR sensors are able to sense magnetic fields and are optimized for use within earth’s magnetic field. An AMR sensor comprises of a thin lm of Permalloy deposited on silicon wafer as a resistive strip. In the presence of a magnetic field the resistance of this resistive strip changes by 2-3%. The magnetic field is detected by using four of these resistive strips to form a wheats [11] tone bridge. This enables the measurement of direction and magnitude of the magnetic field.

AMR sensor based technique exploit the fact that most road vehicle have considerable amounts of ferrous metals in their bodies. This makes magnetic sensors a good option for detecting vehicles. A vehicle, whether it is stationary or moving, creates a disturbance in earth’s magnetic field which otherwise is uniform over several kilometers. This change in earth's magnetic field is used to detect, classify and estimate speed of vehicles. The advantage of AMR sensors is that they can be manufactured in bulk at low cost and mounted in commercial IC packages. They are small in size, highly sensitive, immune to noise and reliable. The problem with existing systems using AMR sensors is that they try to explicitly count or classify vehicles. Due to the exponential drop in detection ability of these sensors with distance, they are generally put in the middle of a traffic lane or at the curb. Then they are able count and classify vehicles in a particular lane. As has been stated several times earlier this assumption will not hold true in Indian circumstances.

Counting algorithms based on some sort of thresholding mechanism will degrade under the chaotic, dense and varied traffic conditions in India. Current classification algorithms developed for AMR sensors will not work effectively due to wide variety of vehicle types, not only cars but large number of two wheelers and three wheelers [12]. Thus, it can be concluded that AMR sensors have cost, exibility and deployment advantages. However, existing techniques that use AMR sensors cannot be directly used in the Indian traffic scenario. Significant modifications are necessary.

2.8. Other traffic estimation techniques

It assumes the presence of a vehicular mobile network or some form of data communication capability. This capability is combined with GPS to generate location time traces [15].Then use several vehicular traces on a particular road segment to make temporal traffic plot which minimizes the loss of spatial and temporal traffic information. A threshold based quadrant clustering mechanism is used to identify current traffic condition. The approach of this work is completely different from ours. We do not assume any data communication capabilities or commuter participation. Also traffic in India is varied comprising not only of cars but also three wheelers, two wheelers and other types of vehicles. It assumes the extensive presence of high end (hence expensive) mobile phones with sensors to perform rich sensing. The idea is to opportunistically use mobiles present with computers as sensors. However, issues like privacy and user participation are still open questions.

Though sensing mechanisms are described, but it is not explained as to how all the sensed data will be processed to give useful information. The paper also introduces the concept of triggered sensing where a low power consuming sensor can be used to activate a more power consuming accurate sensor [16]. For example, Traffic estimation is done using cellular localization to trigger GPS sensing. This concept can be adapted in our system where we can use a single magnetic sensor to trigger other magnetic sensors when sensor values remain above a certain threshold for a specific amount of time. Or we can use an acoustic sensor to trigger sensing of AMR magnetic sensors. In this way sensor nodes can conserve energy and get active only during possible onset of congestion.

3. SENSOR PLACEMENT STRATEGY

3.1. Node deployment strategies

The deployment strategy depends mainly on the type of sensors and the application. The following deployment strategies are generally used in WSNs.

The lifetime of a network is highly dependent on the nodes arrangement that in turn influence energy consumption in WSNs. There are several arrangements, but the most commonly used are triangle, square, and hexagonal in 2-dimensional region. They are generally deployed manually by setting up the nodes in predefined locations to analyze for minimum energy consumption and hence the maximum lifetime of a WSN. A sensor network deployment are generally divided into two groups a dense deployment and a sparse deployment. A sparse deployment would have fewer nodes while a dense deployment has a high number of sensor nodes in the given field of interest. The dense deployment technique is used in circumstances where it is very important for every event to be detected or when it is important to have multiple sensors cover an area. When the costs of the sensors make a dense deployment prohibitive or to achieve maximum coverage using the bare minimum number of sensors the sparse deployments can be used. Initially it is assumed that the sensor nodes are stationary i.e. they stay in the same place where they deployed. New sensor nodes have the ability to rearrange their location after deployment, they are not at a halt and these are known as mobile nodes. Deployment of sensor nodes in triangular, square, and hexagonal tiles are as follows:

3.1.2 Triangle deployment

In this arrangement, the sensors are placed at each corner of a unilateral triangle. Each internal node shares 6 triangles at any point. We represent the area of a triangle in terms of the area of the exterior circle. The radius of the exterior circle d = √ r, where r denotes the side length of the unilateral triangle [25]. The area of the network consisting of N nodes is N √ r2 = N √ d2.

3.1.3. Square deployment

In this deployment, the sensors are placed at each corner of the square. The area covered by the network consisting of N nodes is given by 2Nd2, where d is the radius of exterior circle [26].

3.1.4. Hexagon deployment

A hexagon is a collection of six unilateral triangles. Each hexagon has 6 corners at which a sensor is deployed. [27] The total area covered by N nodes is given by √ 2

3.2. Random deployment

Random deployment is the most practical way of placing the sensor nodes. For a dynamic sensor network, where there is no a-priori knowledge of optimal placement, random deployment is a natural option [20].

3.3. Incremental deployment

The incremental placement strategy is a centralized, one-at-a time approach to place the sensors. The implementation makes use of information gathered through the previously deployed nodes to determine the ideal deployment location of the next sensor node. This can be calculated base station.

3.4. Computational geometry approach

The computational geometry approach is the simplest method for sensor deployment. In this approach, the target sensing region is constructed by a set of grids or polygons thus deciding the node placement.

3.5. Movement-assisted deployment

In certain scenarios, deployment scheme is prone to deviate from the plan, because the actual landing positions cannot be controlled due to the existence of wind and obstacles. For industrial use, where the detection of some part of a machine is required, or in a wildlife sanctuary, one may use mobile sensor nodes, which can move to the desired places to provide the required coverage. In movement-assisted deployment, initially random deployment is performed. Thereafter redeployment of the mobile sensor nodes is performed with incremental optimization [21].

4. OPTIMAL SPATIAL PATTERN

4.1. Node placement algorithm

Node placement is a technique to place the nodes effectively in a simulation area so as to conserve the minimum energy from each node that is intended for transmission of packets or a data. Most of the network considers a communication by deploying the nodes randomly. When the nodes are deployed randomly, there are three issues that mainly are, some nodes are densely deployed at particular region while the other region has got fewer nodes located at farer distances and leaving region will not at all be with the single coverage of node. The drawbacks of such random node deployment is that nodes with dense location, where routing is to take place. All the hops between source and destination in a region of dense location of nodes take part in routing leading to additional utilization of energy from each node, where as

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in the case of nodes at far location, additional energy again is to be spent in transmitting the data to neighbors as well to the destination located at far distances.

On a similar way it is difficult to manage the routing in a region where no nodes are located leading in all the three case, an uneven distribution of energy source and node deployment. First one is, careful node placement can be a very effective optimization means for achieving the desired design goals, and is classified as static approaches. On the other hand, some schemes have advocated dynamic adjustment of node location, since the optimality of the initial positions may become void during the operation of the network depending on the network state and various external factors, We categorize the placement strategies into static and dynamic depending on whether the optimization is performed at the time of deployment or while the network is operational, this approach considers positions of node metrics that are independent of

- the network state or assume a fixed network operation pattern that stays unchanged throughout the lifetime of the network [28].

4.2. Energy model for data communication

Studies have shown that power consumed due to communication contributes to a significant portion of the total power consumed in a sensor network. Hence the energy model presented in [22] has been adopted for studying the effectiveness of the proposed node placement strategies in conserving sensor energy. In our model, the radio energy dissipated in transmitting a single data bit is given by

$$E_{tx} = E_t + E_{amp} * d^2 \quad (1)$$

Where 'E_t' is the energy dissipated per bit in the transmitter circuitry, 'E_{amp}' is the power required in the Transmit amplifier to achieve acceptable signal-to-noise ratio and'd' is the transmission distance.

Thus the total energy required for transmitting a K-bit packet over a distance'd' is given by

$$E_{tx\text{-}total} = (E_t + E_{amp} * d^2) * K \quad (2)$$

The radio energy needed for successful reception of a K-bit packet is given by

$$E_{rx\text{-}total} = E_r * K \quad (3)$$

Where 'E_r' is the energy dissipated in the receiver circuitry to successfully receive a single bit.

Energy model assumptions

- The energy model considered for the study is based on the following underlying assumptions:
- The power consumed by the CPU and sensors in the WSN node is rather a constant and not influenced by the spatial arrangement of sensor nodes. Hence only the power dissipation in radio components is considered for our study.
- The radio energy dissipation to transmit / receive one bit is 50 nJ/bit.
- Energy required in the transmit amplifier is 100 pJ/bit/m^2
- The communication channel is symmetric i.e., the energy spent in transmission from node i to node j is the same as that of transmitting from node j to node i.
- The path loss exponent in transmitting a single data bit over a distance'd' = 2.

4.3. Proposed algorithm

The proposed algorithm considers the drawback of wireless sensor network, in which nodes are deployed randomly. In this paper, the optimized placement of the sensor nodes and relay nodes are done by the circular node deployment technique which isused for reducing the power consumption and thereby increasing the lifetime of the WSN. To ensure the coverage of the network, a sensor placement should satisfy the following constraint. D is the sensing region given by, with R as the radius of the network [29].

Coverage area, throughput maximization, reduced energy consumption and minimum end-end communication delay are the desired performance metrics for wireless sensor nodes deployed in ITS application. In this section the effectiveness of the controlled node placement strategy for the ITS applications is studied.

For the purpose of study we have assumed the following:

The dimensions of the network area are 100m x 100m.

Number of sensor nodes = 16.

- All sensor nodes have the same initial energy level of 350000 Joules which is the energy required to sustain the life of all nodes in the network for a 1 year period.
- The coverage radius of each sensor node = 20 m.
- Nodes in the network are connected such that the Nodei falls within the coverage radius of Nodei-1.
- The order of data transmission / reception is always from Node1…Noden where n is the last node in the network.
- Nodes transmit data every 5 seconds since the data gathered is used for improving vehicle safety and avoiding collisions.
- The data bits processed by each node = 2000.

A sensor consumes Esur =50nJ for transmitting unit of data and k = 100 pJ/bit/m2 for the transmitting amplifier. So the energy consumption of sensor Si in order to be active in the network is given by,

Esur =Eene

As the energy consumed depends on the number of bits transmitted and hence if sensor node transmits k bits, then energy consumed in order to be active in the network is given by, Es (Actual) = K*Eene

At the destination nodes will receive packets; practically the received packets are less than k. Hence energy consumed for receiving packets is given by,

Er(Actual)=(Tp- Pl)

Where Tp is the energy due to transmission and PL is the energy lost due to packet loss [30].

Similarly energy consumption of sensor Si in transmitting a unit of data packet to neighbor node is given by

Enr = Es (Actual)+nn EIdi2

4.4. Simulation

The simulation is carried out in a QualNet simulator. AODV is the routing protocol that mainly concentrates on node deployment technique. After several rounds of routing packets through AODV, simulation results demonstrate that energy consumption with circular deployment of nodes certainly is efficient and less as compared with random deployed nodes [31][32]. Proposed algorithm tries to save the energy of a network, covering maximum area with increase in lifetime of a network. Results obtained are plotted for random and circular deployment of nodes on various parameters. It is clear from the simulation that amount energy left for the circular pattern is more.

5. CONCLUSIONS

In this paper we have proposed the spatial pattern of sensor nodes are done by the circular node deployment techniques for a typical transportation surface. Based on our results we can conclude that sensor placement for any ITS application should be based on topography of the region deployed rather than the random spatial selection which is usually adopted in sensor networks. The study provides insights into the coverage area maximization and the indirect cost benefits due to reduced number of deployed sensors in case of optimal spatial placement and to develop the researcher for more energy efficient strategies for their application and usages.

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