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Abstract

Objective: The objective of this study was to examine and propose the use of wireless sensor networks for people crowd detection in resource constrained environments such as developing economies.

Methodology: A systematic review was carried out on current technological trends and application of Wireless Sensor Networks (WSNs) in crowd detection. For this study, focus was on WSN implementation in developing economies, where infrastructure is underdeveloped and people crowds are dynamic and spontaneous. Based on a requirement analysis and knowledge of the inherent challenges of WSNs, a WSN implementation for people crowd detection was proposed.

Findings: Most studies in crowd detection using WSNs, have been in the area of non-people crowds. However issues critical to deployment of WSNs for people crowd detection in developing countries include: the uncontrollable nature of people crowds, under developed physical infrastructure and the inherent challenges of power, computational capacity and broadcast communication characterizing WSNs. Achieving people crowd detection using WSNs therefore, calls for special attention.

Recommendation: To ensure effective people crowd detection, requires taking into consideration connectivity, scalability, performance, security, accuracy and resource utilization of WSNs.

Keywords: *Wireless sensor networks, crowd detection, people crowds*

1.0 Introduction

Wireless Sensor Networks (WSNs) are a group of spatially distributed sensor nodes or motes interconnected by a wireless communication infrastructure and deployed to collect data about a physical environment. Unlike image based sensing, non-image based wireless sensing have been found to be less resource intensive compared to the image based detection. The potential and ability of WSNs to measure environmental conditions like humidity, pollution, temperature and sound have fuelled the concept of smart cities (Lai et al., 2020) and smart world (Taylor et al., 2018; Liu et al., 2019). Their self-organizing characteristic, ease of deployment and fault tolerance have led to growing interest in deployment of WSNs for various applications.

WSNs consist of an interconnection of autonomous sensor equipped devices to sense, process and communicate data between each other. A sensor node comprises of: A sensing unit, processing unit, communication unit, and optionally a positioning and mobility system as shown in figure 1. The sensing unit collects analog data from the physical environment and the ADC performs an analogue to digital conversion of the collected data. Intelligent data processing and manipulation is performed by the processing unit. While the communication unit consists of a radio system that is used for data reception and transmission using short range radios. The battery is used to power the entire system. The optional positioning system determines the node location, while the mobility system allows nodes to have movement without being restricted to single-hop communication ranges.

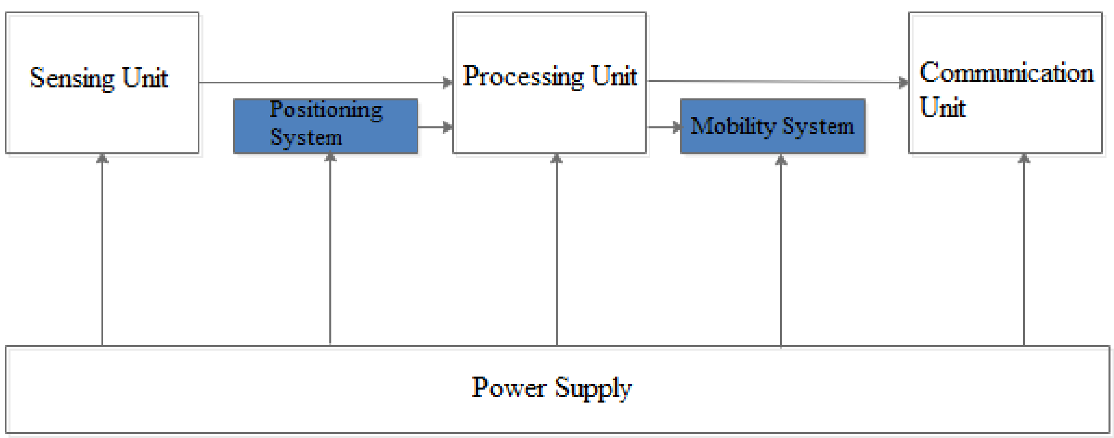

Figure 1: Main components of a sensor node

In a clustered WSN, the sensor components combined, make possible the detection and communication of environment data via the cluster heads to the sink for analysis as shown in figure 2.

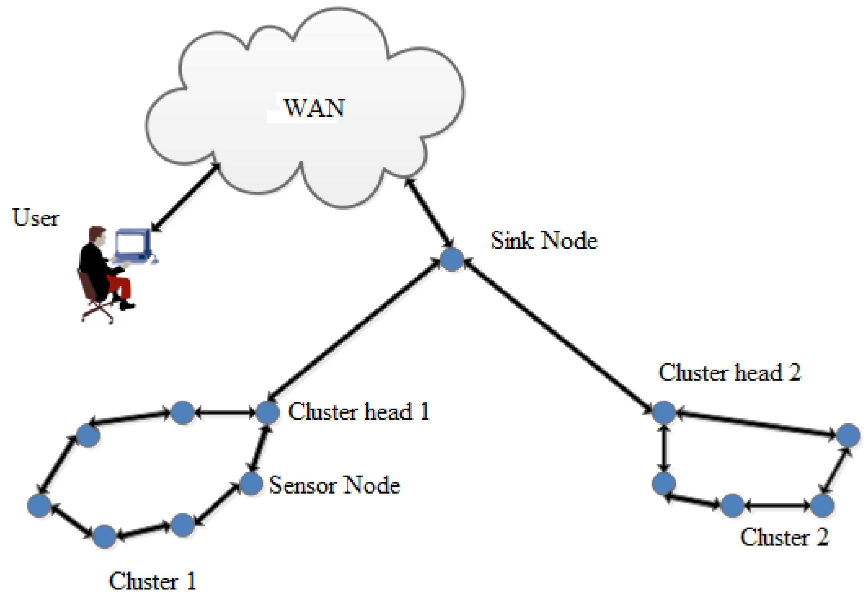

Figure 2: Generalized clustered wireless sensor network

Advances in WSN technologies have as a result attracted increasing interest from a varied number of IoT applications as published in recent surveys (Alemdar & Ibnkahla, 2007; Balaji, Nathani & Santhakumar, 2019). Crowd detection is an area that has and can further leveraged on the power of WSNs. For example, a system that consists of various sensor nodes distributed within a Region of Interest (ROI) was proposed to detect and monitor crowd behavior (Kasudiya, Bhavsar & Arolkar, 2020). The system is activated to give guidance for crowd evacuation. Barricades were constructed to provide for evacuation from different sectors of the region. Pilgrims required to first register so as to acquire wrist bands that are also activated to provide the health state of each pilgrim. Navigation screens or LCDs were used to disperse crowds and a Centralized Sensing and Monitoring Units (CSMU) deployed for crowd control in every sector. BorderSense (Sun et al., 2011) on the other hand is a hybrid WSN architecture intended to curb human involvement in crowd detection. It utilizes an advanced sensor technology that includes multimedia sensor networks. It employs a three layered design with three different types of sensors: Cameras, mobile and underground seismic sensors. It is only clear that this approach is resource intensive.

Crowd distribution was also estimated using WSNs based on a two phased iterative process (Yuan et al., 2011). The two phases of detection and calibration involved division of RSSI data into levels and then elimination of noise respectively. The result was an accurate, efficient and consistent crowd detection performance. Literature has also been published on people counting approaches: Son et al. described a people counting system suitable for protecting the ecosystem of mountain areas (Son et al., 2007). The system used photo beam sensors deployed at entry, exit and turning points of paths around the ROI. The sensor nodes collects data about the number of people visiting and via a gateway forwarded the collected data to other networks for analysis. A distributed people counting system using WSNs was also proposed in (Senti, 2011). While other people counting approaches have used Wi-Fi technology (Depatla & Mostofi, 2018; Zhao et al., 2019).

Achieving smart city status through deployment of WSNs in resource constrained economies brings quite a considerable number of difficulties. Inherent challenges of WSNs, the chaotic nature of people crowds and poor communication infrastructure were highlighted as challenges in developing economies (Obbo, Nabaasa & Ariho, 2022). With this line of thought, this paper proposes a people crowd detection system for resource constrained environments using WSNs. The paper highlights core components, constraints and guidelines for effective implementation of WSNs for people crowd detection.

2.0 People Crowd Detection

Research in detection and by extension management of people crowds has increasingly attracted interest because of the growth in the events industry, vandalism of public infrastructure by disgruntled individuals during political demonstrations and importantly, the need to curb the spread of disease pandemics. Despite, technological and infrastructural progress in many countries however, people crowds remain of particular concern for developing economies. This is played up by the poor communication infrastructure and threat on hardware by uncontrollable people crowds.

Wireless sensor networks represent a significant advancement over traditional crowd detection methods. Wireless sensor networks unlike many traditional solutions, are non-invasive and are self-configuring. Furthermore, WSNs represent a more economical alternative when compared to traditional personnel rich and resource intensive technologies such as vision based approaches. In addition, they can be deployed in hard to reach areas, even prior to the detection processes. When deployed as Underground Wireless Sensor Networks (UWSNs), the network parts from traditional WSNs in that both the sensing nodes and transmitting medium are underground. Each node in an UWSN, contains all the necessary sensors, processors, radio, antenna and memory. This makes their deployment and implementation relatively cheaper compared to many underground solutions. A strong point with UWSNs, is concealment of nodes from public view, ease of deployment and timeliness of sensing data (Akyildiz & Stuntebeck, 2006). In addition, because each UWSN node can wirelessly forward data directly to the central sink without the need for data loggers, single points of failure are minimized and hence reliability is improved.

3.0 People Crowd Detection in Developing Countries

This section presents requirements to people crowd detection using WSNs in developing countries together with the associated constraints and suggested solutions. The unique challenges relate to the dynamics of people crowds in developing countries and shortfalls of WSNs. Limitations of WSNs have been highlighted in literature and include: dynamic topology, limited data rates, different traffic intensities, application specific networking, energy constraints and time synchronization (Kosanović & Stojčev, 2011). It is also evident that people crowds in developing countries can turn out to be both hard to control and violent. These factors emphasize the need for attention to be given to people crowd detection in developing countries. In this paper; connectivity, scalability, security, performance and resource utilization are all discussed in the context of underdeveloped infrastructure and uncontrollable nature of people crowds characterizing developing countries and by extension resource constrained environments. Requirements and constraints of the options are also briefly highlighted.

3.1 Connectivity

Although WSNs can work autonomously, for many applications, they require connectivity to either a Local Area Network (LAN), Metropolitan Area Network (MAN), global Internet or application specific gateways to route sensor data for remote analysis. Internet of Things (IoT) is a moving force for technology and describes an inter-connection of objects and people, embedded with sensors and software for the purpose of exchanging data. Integration of WSN to IoT has been seen as an enabler to achieving the apical of many applications. Integration of WSNs in IoT is therefore inevitable. However, IoT is mainly implemented on TCP/IP, which has been perceived to be too resource intensive for WSNs. This has inspired work in a number of enabling technologies: 6LoWPAN Gateway was proposed to enable integration with IP version 6. IPv6 is a fast emerging addressing protocol (Schrickte et al., 2013). Tiny TCP/IP configurable protocol stack that occupies only a few kilobytes of code space and occupies only a few hundred bytes of memory space. It has been proposed as an alternative to a fully-fledged TCP/IP (Han and Ma, 2007).

While the micro SOA-model which uses Mobile IP (MIP) has been implemented to enable movement of mobile devices across different networks while maintaining their IP addresses. It thus simplifies IP address management. Compression of XML and JSON messages reduce the resource overhead for devices with 48 KB of ROM and 10 KB of RAM (Sleman and Moeller, 2010). Spatial IP addressing leverages on the ability of sensor nodes to determine their own location through localization to solve the problem of address assignment (Dunkels, Alonso & Voigt, 2003). While header compression techniques, compress header information using simple pattern marching techniques in addition to utilizing only a small number of UDP ports for sensor datagrams. Application overlay routing reduces routing overhead by enabling attribute based routing, while distributed TCP cashing (DTC) instead of relying on TCPs' resource intensive end to end retransmission, requires only a local retransmission scheme to reduce energy consumption (Dunkels et al., 2004).

Overall, in addition to the relatively less developed infrastructure, the fraction of the budget allocated to different government sectors in developing economies cannot be relied upon to effectively provide all intended services. Connectivity options that minimize costs will logically be the ones of choice.

3.2 Scalability

Scalability is an important aspect in designing WSNs. A WSN should self-configure and be robust to topological changes. A scalable WSN should also accommodate nodes for increasing network size at a later stage. WSN scalability considers an integrated view of both software and hardware. Software scalability involves reliability in command dissemination and management of large volumes of data – transfer, and algorithms for their analysis. Data transfer can take the form of single hop or multi-hop. In multi-hop data transfer, data exchange is between nodes not within the same radio range. Their strong point is that they require less energy to transmit data over long distances compared to their counterparts – the single hop, where data transfer is between adjacent nodes within the same radio range. Hardware scalability on the other hand is determined by the hardware capability to support network growth over time without necessitating replacement. It is dependent on sensitivity and range of MEMS sensors, power usage and communication bandwidth of the radios. Hardware scalability is especially critical for environments realizing developments that should accommodate additional facilities.

Recent works on scalability of WSNs include: Scalable Zigbee expansion solution and efficient routing algorithms (Zhong et al., 2018; Elsmany et al., 2019). These solutions, when incorporated into sensor networks, will enable increased coverage area of the ever expanding urban cities and present opportunities for managing increased number of people crowds.

3.3 Performance

Performance of a WSN measures how well a WSN runs. It is evaluated based on several criteria. Optimizing network performance is necessary to reduce energy consumption in addition to network redundancy. To optimize performance therefore, WSN designs and deployment aim at attaining the following:

- Minimizing energy consumption,
- Increasing node lifetime,
- Extending coverage, and
- Minimizing number of nodes required.

Clustering is a method that has been used to prolong WSN lifetime. It involves grouping sensor nodes into clusters and electing a cluster head for each cluster through which all traffic from the cluster are forwarded. Cluster-based WSNs provide more efficient network communication, allows for better topology management and hence more energy efficient.

As a result, clustering has attracted a lot of research interest. For example work has been carried out in clustering of WSNs to increase network life span and minimize energy waste (Sharma and Ahmed, 2021). To improve network performance in people crowd detection, an urban city can be subdivided into manageable clusters with respective cluster heads.

Critical to network efficiency, are the routing algorithms implemented. Provisioning of energy efficient routing algorithms is inevitable to minimize, packet loss, ensure end to end delivery and minimize energy consumption. To improve network performance, energy efficient routing algorithms have been proposed (Guleria & Verma, 2019; Nakas, Kandris & Visvardis, 2020). There have also been efforts to make use of multiple paths (Boukerche & Darehshoorzadeh, 2014), consider dynamics of the link between the source and destination (Mostafaei, 2018), combination of clustering and sink mobility (Wang et al., 2019) and employing type1 and type 2 fuzzy logic to minimize the burden imposed on cluster heads (Nayak & Vathasavai, 2017). Formulations to achieve the above listed objectives however, compete with each other and only a tradeoff solution can be achieved. For example, simple aggregation protocols can only be deployed in attack free environments. The routing algorithm implemented will be highly dependent on the purpose of the people crowd detection system.

3.4 Security

WSNs are self-healing, self-organizing and autonomous in nature. The rapid growth in their applications and data communications means sensor data can be vulnerable to a number of attacks. The limitations in computation, energy, communication and memory of sensor nodes make it difficult to ensure security and privacy. And also since WSNs are no longer only applied within enclosed environments, they are vulnerable to attacks at both node level and communication channel. Dener in his work classified these attacks as: physical, link, network, transport layer attacks (Dener, 2014). Given that security is critical in many sensor network applications, the need to address security issues associated with WSNs at all layers of communication.

Ongoing work in security of WSNs include: designing of low cost sensors resistant to harsh environments, designing sensor WSNs with high capacity together with fast and secure data flow. Existing security solutions in WSNs include: Encryption schemes, security protocols and Certificate less Effective Key Management (CL-EKM). While the focus of node level solutions have been to minimize unauthorized data injection during data aggregation and anomaly detection. Encryption constitutes one of the most common tools used in provision of security services in WSNs. The small memory, limited energy, and weak processors of sensor nodes in addition to the harsh environments in which nodes are deployed introduce a number of problems in implementing traditional encryption schemes. As a result, a number of encryption schemes have been proposed over time. Advanced Encryption Standard (AES) runs on 10, 12 and 14 rounds with 128, 192 and 256 bit sizes.

It has however been found to be vulnerable by researchers (Dusart, Letourneux & Vivolo, 2003; Weiß, Heinz, & Stumpf, 2012; Lepoint, et al., 2013). Data Encryption Standards is a block cipher algorithm that takes plain text in blocks of 64 bits and converts them to ciphertext using keys of 48 bits. Its variants 3DES, DES-X were designed to counter the shortfalls of DES (Leander et al., 2007). Blowfish algorithm is a symmetric-key block cipher designed to replace the DES. It was intended to provide a fast, and free drop in alternative to DES. And its complex key schedule makes the algorithm stronger. Compared to DES, it is secure for small scale applications (Radhappa et al., 2018). However, like DES, Blowfish is not a good fit for large scale deployments.

Security protocols define the set of rules that determine how processes interact to provide a given security service (Aseri & Singla, 2011). Popular WSN security protocols include: SPINS, TINYSEC, MiniSec, Link Layer Security Protocol (LLSP), Light weight Security Protocol (LISP), Location aware end to end security (LEDS), Location encryption and authentication protocol (LEAP), ZigBee, and Intrusion tolerant routing for wireless sensor networks (INSENS). Certificate less effective Key Management (CL-EKM) is a public key based scheme proposed for WSNs (Kamble & Jog, 2017), while the Enhanced Certificate less Effective Key Management (ECL-EKM) was proposed to solve the management problems associated with both the symmetric and asymmetric key based schemes (Mall, Konaté, & Pathan, 2017). Certificate less key management schemes are designed to eliminate the need for certificate based public key distribution and counter single point of failure characteristic of traditional key management schemes. These traditional schemes may find challenges when implemented for dynamic networks such as WSNs.

The current state of urban streets and road users in developing economies exposes sensor nodes to destruction and attacks by adversaries or disgruntled individuals. While exposed sensor nodes in addition to other vulnerabilities, are prone to false data injection and physical destruction. Data aggregation algorithms therefore need to be both efficient and resilient against compromise.

3.5 Resource Utilization

Nodes in WSNs are inherently resource constrained with regard to communication bandwidth, processing speed and storage capacity. As a result, a number of approaches have been proposed to tackle the energy consumption problem of battery-powered nodes. These approaches include: radio optimization, data reduction, sleep/wakeup schemes, energy efficient routing and energy repletion (Rault, Bouabdallah & Challal, 2014; Engmann et al., 2018). Radio optimization approaches attempt to reduce energy dissipation resulting from wireless communication. To do this, research efforts have been invested in modulation schemes (Amutha, Sharma and Nagar, 2020), power transmission (Dong et al., 2019; Srivastava and Singh, 2022) and antenna direction (Dang et al., 2015; Kumai, Kumar & Bajaj, 2017; Kumari, Kumar & Bajaj, 2018).

Data reduction minimize data that could have otherwise been delivered to the sink. Unnecessary samples and sensing tasks are reduced through appropriate aggregation schemes (Vinodha and Mary, 2019), data compression (Srisooksai et al., 2012; Sheltami, Musaddiq & Shakshuki, 2016; Razzaque, Bleakley & Dobson, 2013), network coding (Ostovari, Wu and Khreishah, 2014) and adaptive sampling (Jain & Chang, 2004). In addition to reducing data traffic, these efforts also result into reduced network latency. Sleep/wakeup schemes schedule radio state depending on network activity, while topology controls deploy redundant nodes to ensure space coverage. Some nodes of the WSN are deactivated while ensuring normal network coverage. This scheme is appropriate for networks that do not require activation of all nodes at the same time. Passive wake-up radios enable power hungry nodes to be used for data transmission only.

Very important to the design of wireless sensor networks is network topology. For example, determination of which sensor nodes should be closest to the sink. This is because nodes closest to the sink route more traffic than any other on the WSN and hence have a higher energy depletion rate. Energy efficient routing protocols (Mohamed et al., 2018; Rai & Rai, 2019) mitigate this challenge through implementation of cluster architectures for both heterogeneous and homogeneous WSNs (Rostami et al., 2018; Arjunan & Pothula, 2019). When energy is used as a routing metric during route selection, preference can be given to sensors with more energy (Zagrouba & Kardi, 2021). Other measures such as multipath routing (Hasan, Al-Rizzo and Al-Turjman, 2017), sink mobility (Hamida & Chelius, 2008), and relay node placement (Vallimayil et al., 2011) can all be employed to improve network performance.

Battery charging mechanisms have also been proposed to enable recharging of sensor batteries without human intervention (Prakash & Saroj, 2019). Wireless charging makes possible wireless transfer of power between devices. The technique employs either electromagnetic radiation (EM) or magnetic resonant coupling. Magnetic coupling has been considered most promising because of their higher efficiency with short ranges of several meters. Wireless charging fits the need of sensor deployments where it may not be possible to regularly have a physical connection with the nodes such as where nodes are embedded in concrete or below the ground surfaces.

3.6 Accuracy

The need for precision in many applications has inspired research in accuracy of positioning algorithms in WSNs. Node localization is for example used in determining the location of a node or subset of nodes. Published literature highlight shortfalls and strengths of traditional positioning and localization algorithms. Traditional localization mechanisms include: Time of Arrival (ToA) (Shen, Molisch & Salmi, 2012), Time Difference of Arrival (TDOA) (Ho, Lu & Kovavisaruch, 2007), Angle of Arrival (AOA) (Zhang et al., 2012) and Received Signal Strength Indication (RSSI) (Wang & Yang, 2011). RSSI has been considered simplest and cost effective of range based positioning algorithms because it does not require additional dedicated hardware (Bal et al., 2009; Jia & Guan, 2018). RSSI based approaches trade off accuracy for low complexity and power saving.

4.0 Proposed WSN for People Crowd Detection

A generalized representation of the proposed people crowd detection system using WSNs is illustrated in Fig 3 below. The proposal is biased towards resource constrained developing economies.

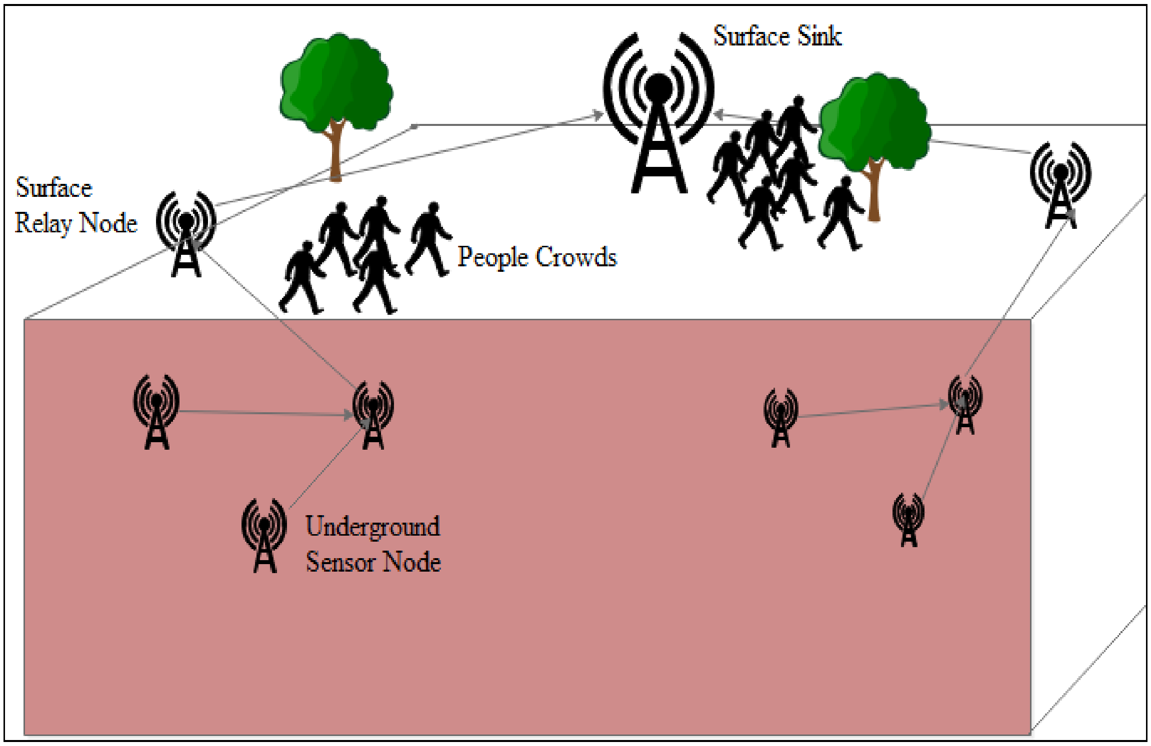

Figure 3: Underground WSN for People Crowd Detection

Underground Wireless Sensor Networks employ three types of communication: underground to over ground, underground to underground and above ground to underground communications. An Underground Wireless Sensor Networks (UWSN) is suggested because it addresses security concern of node exposure. Challenges of node security and deployment complexity associated with people crowd detection in developing countries can be mitigated since the sensing nodes are out of view of the crowds. And deployment of UWSNs is relatively easy. They are also less affected by interference. A clustered WSN communication is preferred because in addition to other advantages of clustering, it presents opportunity for subdivision of the ROI into manageable sectors.

Network topology defines how various nodes, devices, and connections on a network are physically or logically arranged in relation to each other. WSNs support topologies that include: bus, star, ring, circular, meshed and grid topologies. The Grid topology has been considered an appropriate topology because it is energy efficient and its design enables functionalities with minimal maintenance requirements (Sharma, Verma & Sharma, 2013). Localization in WSNs help determine the location of sensor nodes. Work has been done with the objective of designing low-cost, scalable, and efficient localization schemes (Wang, Ghosh & Das, 2010; Cheng, et al., 2012; Coluccia & Fascista, 2019; Sneha & Nagarajan, 2020). Time of Arrival (ToA) and Time Difference of Arrival (TDoA) are localization approaches that have high accuracy, high complexity, time synch and high power. On the other hand, RSSI based estimators provide low complexity, no time for synch, low power but with low accuracy. Therefore whenever accuracy is not critical, RSSI is an approach of choice.

With regard to requirement considerations highlighted in Section 3 above, Tiny TCP/IP requires only a few kilobytes of code space and memory since existing infrastructure already support the TCP/IP model. Overall, the architecture takes into consideration the limited infrastructural resources that is characteristic of many developing economies. It also provides for scalability to allow later modifications and expansion since extension of the WSN requires only minimal physical connectivity to the existing deployment. In addition, because UWSNs have most of the infrastructure underground, vulnerabilities resulting from exposure of sensing infrastructures are minimized. As a result therefore, the proposed WSN presents a step towards achieving efficient detection of people crowds in resource constrained environments.

5.0 Conclusion

Advances in micro-electromechanical technologies have enhanced application of WSNs in crowd detection. Although WSNs have been employed in crowd detection and to an extent in people crowd detection, their application in developing economies have been hindered because of underdeveloped infrastructure and the nature of people crowds therein. People crowds are also spontaneous and dynamic in nature. In addition, despite registered progress in WSNs, crucial issues that still require special attention in resource constrained economies include: the need for dense node deployment including regions that are sometime hazardous and prone to failures, broadcast nature of WSN communication, limited power, memory and computational capacity of sensor nodes. These factors present areas that require special attention for resource constrained developing countries. This paper highlighted the need for special attention to be given to people crowd detection using WSNs in developing countries.

6.0 Recommendations

This research proposed a WSN based architecture that can continuously keep track of crowd activities. In case of people crowd presence, the WSN can provide notification via the sink. Data generated can later be integrated with other navigation systems to enable appropriate action such as safe evacuation or appropriate service delivery. By proposing the architecture, the researchers intend to minimize the number of potential casualties from incidences and provide support for proper planning using minimal resources. Owing to the above requirements for people crowd detection, a tradeoff option has to be made to ensure appropriate and feasible detection of people crowds. People crowd detection in resource constrained environments have to take into consideration available resources, incorporate the component of people crowd dynamics and maximize available infrastructure.

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