Mobile Phone Based Acoustic Localization for Wireless Sensor Networks

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Abstract—In wireless sensor networks, localization techniques are required for finding physical location of the sensor nodes. Most of the existing 2D and 3D localization schemes are reference based. Finding physical locations of sensor nodes in an application field with only 2D or 3D physical topology map or logical topology map is arduous and tedious. This paper refers to mobile phone based acoustic localization technique for wireless sensor networks, which can be used along with physical topology map or logical topology map. In our proposed method, deployer searches the sensor node by using Doppler effect of acoustic wave, which is generated by his mobility. The proposed method helps in quick localizing of the sensor nodes without consuming much time and it has been implemented, tested by using mobile phone and IITH motes, the in-house developed sensor nodes.

Index Terms—Acoustic technology, Localization, Doppler effect, Network topology.

I. INTRODUCTION

For most of the WSN applications like pollution monitoring, marine monitoring, forest fire location detection and surveillance security, sensor nodes are deployed randomly. Localization techniques are needed to know the exact location of sensor nodes.

In paper [1], we proposed a mobile phone application called as Deployment Adviser tool for the purpose of field deployment of sensor nodes. The Adviser tool shows logical network topology map, redundant relay nodes and hot-spot relay node in the network as shown in Fig. 1. The Adviser tool gives advise to increase the network lifetime by distributing the power consumption among all the nodes in the network. To increase the network lifetime extra relay nodes around the hot-spot relay node (node which consumes more energy compared to all nodes in network) have to be placed. In real field deployment removing redundant relay nodes and placing extra relay nodes around hot-spot relay node are manual operations (Fig. 2), and to do this work exact physical locations of nodes are required. Normally labeling method (marking each node with unique id or symbol) is used for removing redundant relay nodes and placing extra relay nodes around hot-spot relay node. In highly dense network, finding particular labeled node in real time by using only logical network topology map or physical network topology map is time consuming and difficult task. There is a need of additional localization system connected to network topology mapping system, which makes the task of finding physical location of sensor nodes easy. This motivates us to develop mobile phone based acoustic localization system for wireless sensor networks.

Most of the existing Received Signal Strength Indication (RSSI) values based localization algorithms [2]-[5], acoustic localization algorithms [6], [7] are reference based. These localization algorithms consider a known location as reference point to create localization map. The proposed work helps in finding sensor nodes location by using acoustic wave technology. Acoustic localization techniques are more desirable than RF based localization techniques, the reason being the relatively low speed of acoustic waves that causes the localization system to be less sensitive to errors in time-of-flight measurements.

Fig. 1: Network topology shows redundant and hot-spot nodes

The proposed application will be useful when servicing (sensors replacing, trouble shooting of sensors circuitry and etc.) is required for a particular sensor node in a sensor network.

Authors of [8] and [9] discussed about Time Of Arrival (TOA) based algorithm for finding distance between two mobile phones. Here to find distance, mobile phones transmit and receive chirp signals (acoustic waves) and matched filter detection will be done to detect correlation peaks of received acoustic wave. TOA is obtained by calculating time difference between correlation peaks of received acoustic waves. Authors of [10] discuss about finding direction between two mobile phones by using Doppler effect. They used pulse-pair method to calculate Doppler effect, where both devices transmit and...
receive multiple pulse type acoustic waves (pulse type chirp signal). Direction between two mobile phones is estimated by detecting change between transmission, reception acoustic pulse intervals.

In case of wireless sensor networks, usually nodes have poor computation and processing capability compared to mobile phones. To generate and detect received acoustic waves, extra complex hardware is required which can be interfaced with sensor nodes. In [11] authors proposed acoustic self-localization method for distributed sensor networks and authors of [12] proposed sensor node localization using mobile acoustic beacons. For detecting acoustic wave they used special designed complex hardware i.e. custom sensor board with microphone, ADC, FPGA and DSP interfaced with Mica2 mote [13]. Increase in complexity of hardware increases power consumption, which lead to reduction in sensor node’s lifetime.

Our method of localizing sensor node in sensor network is direction oriented method. In proposed acoustic localization technique we developed a low complex acoustic module (designed with simple RLC resonant circuit followed by an amplifier). In our system, Doppler effect is used to find direction between sensor node and mobile phone (carried by deployer), where sensor node will emit acoustic wave. Doppler effect is caused by deployer’s mobility. To emit acoustic wave sensor node is equipped with an in-house developed, low complex acoustic module.

Rest of the paper is organized as follows section II describes direction finding method and section III describes implementation of proposed method. Section IV explains experimental results and analysis. Section V concludes the paper.

II. DIRECTION FINDING METHOD

Doppler effect is a well known wave characteristic. Consider a scenario, where a sound source is stationary and listener (observer) is mobile (sound refers acoustic wave, we use sound and acoustic interchangeably hereafter). Due to Doppler effect when listener move towards (approaches) to the sound source, he observes received frequency of the sound is higher than original (actual) frequency transmitted by source. When listener moves away from sound source he observes received frequency of sound wave is lower than actual frequency transmitted by source as shown in Fig. 3. Let the speed of sound wave be $v_s$, which is transmitted from the sound source and let the average moving speed of listener be $v_l$ as shown in Fig. 4. Let $\theta$ be the angle between sound source and listener velocity (i.e. angle between $v_l$ and $-v_s$). The relative speed of sound wave observed at listener is $v_{ob}$. When listener is moving at an angle $\theta$ then $v_{ob} = v_l \cos \theta + v_s$. When listener approaches the source $\theta \in \{ \theta_l \mid 0 \leq \theta \leq 90 \}$ then $v_l \cos \theta$ will be positive, resultant velocity $v_{ob}$ is $v_{ob} \geq v_s$. And when listener moves away from sound source $\theta \in \{ \theta_l \mid 90 \leq \theta \leq 180 \}$ then $v_l \cos \theta$ will be negative, resultant wave velocity $v_{ob}$ is $v_{ob} \leq v_s$. Received sound wave frequency $f_l$ at listener will be calculated by using below equation (1),

$$f_l = \frac{v_{ob}}{v_s} \times f_s$$  \hspace{1cm} (1)$$

$$v_{ob} = v_s + v_l \cos \theta$$

Then above equation becomes,

$$f_l = (1 + \frac{v_l \cos \theta}{v_s}) \times f_s$$

$$f_l = f_s + f_d$$  \hspace{1cm} (2)$$

Where $f_d = (\frac{v_l \cos \theta}{v_s}) \times f_s$

$$f_s = \text{source transmitted sound frequency}$$

$$f_d = \text{Doppler frequency}$$

From equation (3) Doppler frequency $f_d$ will be positive when listener approaches sound source. The observed sound wave frequency at listener is $f_l \geq f_s$ in equation (2). When listener moving away from sound source, Doppler frequency $f_d$ will be negative and the observed sound wave frequency at listener is $f_l \leq f_s$ in equation (2).

In proposed method, sensor node is stationary sound source and mobile phone carried by deployer is mobile listener (observer). When deployer move towards the sensor node (which is emitting acoustic wave with constant frequency), due to Doppler effect mobile phone receives sound with higher frequency than actual frequency $f_s$ and $f_l \geq f_s$. When
deployer moves away from sensor node, mobile phone receives less frequency than actual frequency $f_s$ of sound source i.e. $f_l \leq f_s$. Thus, by considering Doppler effect, mobile phone can give advise to deployer i.e. whether he is moving towards the sensor node or away from sensor node. From this advise it will be easy to locate sensor node in dense sensor network.

III. ACOUSTIC LOCALIZATION IMPLEMENTATION

Proposed acoustic localization system is depicted in Fig. 5. To implement whole system, Android 5.1.1 platform is used for mobile application. TinyOS-2.1.1 is used for sensor network programming and JAVA is used for server programming. To create sensor network we used IITH motes as sensor nodes [14]. We use network topology map from Adviser tool application. Each sensor node in the network is equipped with acoustic module which is simple and low cost circuitry as shown in Fig. 6.

A. Signal selection

Acoustic signal used for localization should be selected such that it should be compatible with all commercial available speakers and microphone devices i.e. it should be in audible range (20-20000 Hz). Selected acoustic signal should have high immune to noise and it should be possible to generate with simple and low cost circuitry. Ambient sound noise levels are high at lower frequency range (20-10000 Hz) compared to higher (10000-20000 Hz). Therefore, 20 kHz frequency is chosen for the proposed method. Sensor nodes usually have very low computation capability due to minimal on-board resources. Now a days mobile phones opened the feasibility for highly intensive computations by utilizing extensive on-board resources such as huge internal memory, multiple radios etc. Acoustic wave generation is simpler than receiving and it’s processing. Thus, sensor nodes are selected as sound wave sources and mobile phone as listener.

Sensor node is programmed to generate square wave from one GPIO (General Purpose Input/Output) pin. Interfaced circuitry converts 20 kHz square wave to 20 kHz single tone sinusoidal and it amplifies sinusoidal which is input for speaker as shown in Fig. 7. From speaker 20 kHz sound will be emitted.

IV. EXPERIMENTAL RESULTS ANALYSIS

To find location of the sensor node, deployer chooses node id (hot-spot or other nodes id) from network topology in Adviser tool. The mobile will send chosen node id to the server to which base station is connected. Base station or sink node of that network will get that particular node id from server through serial port. Whenever base node gets node id, it unicasts a command packet to that particular node in the network. When sensor node receives command packet from base node, it emits acoustic signal for finding direction between mobile phone and sensor node. Mobile phone continuously listens sound from sensor node. Received acoustic wave frequency $f_l$ will be computed in mobile phone continuously by using Fast Fourier Transform. Original sound source frequency $f_s$ information will be stored in mobile phone. From equation (2), by subtracting original sound source frequency $f_s$ to received frequency $f_l$, Doppler frequency shift $f_d$ is calculated. If $f_d$ is positive then mobile phone plays voice and displays in text "APPROACHING" and "LEAVING" when $f_d$ is negative as shown in Fig. 8 and Fig. 9.
temperature is \( v_s = 346 \text{ m/s} \) [16] and sensor node emits sound with frequency \( f_s = 20 \text{ kHz} \).

A. Case 1: Approaching

Let consider listener is moving at an angle \( \theta = 89^\circ \) between line joining from sensor node and listener moving direction. By substituting average human walk speed \( v_l \), sound wave speed \( v_s \) and angle \( \theta \) values in equation (3) Doppler frequency \( f_d \) is calculated. Resultant Doppler frequency \( f_d = 1.41 \text{ Hz} \) and actual frequency transmitted by source is \( f_s \approx 20000 \text{ Hz} \). Frequency received at listener \( f_l \) is calculated by substituting \( f_d, f_s \) in equation (2) i.e. \( f_l = 20001.19 \text{ Hz} \) and it is greater than \( f_s \). The Result is approaching and mobile phone plays voice and displays "APPROACHING" in application GUI as shown Fig. 8.

B. Case 2: Leaving

Now consider that listener moving with an angle \( \theta = 91^\circ \). By substituting average human walk speed \( v_l \), sound wave speed \( v_s \) and considered angle \( \theta \) values in equation (3) we get Doppler frequency \( f_d = -1.41 \text{ Hz} \). The actual frequency transmitted by source is \( f_s = 20000 \text{ Hz} \). Frequency received at listener \( f_l \) is calculated by substituting \( f_d, f_s \) in equation (2) and result is 19998.59 Hz. It is less than \( f_s \) and result is leaving, therefore mobile phone plays voice and displays text as "LEAVING" in application GUI as shown Fig. 9.

V. Conclusion

In this paper we proposed an acoustic localization method, which finds physical location of the sensor node in a sensor network with help of the network topology map. The proposed method is implemented and tested with IITH motes and mobile phone. It can be used along with 2D or 3D localization map also. It reduces deployer onus and facile for deployer in searching the sensor nodes in the network.

The current system shows whether deployer moving towards or away from the sensor node. In future we want to improve the system such that the mobile phone application shows exact direction with an arrow mark and it can give advise to the listener to move towards the sensor node.

REFERENCES


