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Wi-Fi Radar Placement for Coverage in Collapsed Structures

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***Abstract*—Recently, IoTs witnessed tremendous growth and have become integral to our daily lives. Wi-Fi, which was once a way of enabling convenient wireless access to the Internet, is now being used for various novel IoT applications. Researchers are focusing on exploiting the channel state information output from Wi-Fi and changing existing Wi-Fi infrastructure into a Wi-Fi radar which can be used for various applications. This paper proposes a novel Wi-Fi radar system placement approach for better coverage in collapsed structures. The objectives are first to find a debris environment followed by wireless signal mapping to debris and then to compute better Wi-Fi radar coverage with the signal to noise ratio larger than a predefined threshold. This method computes the coverage by single Wi-Fi based on Wi-Fi radar approach and then partition the whole debris model into subregions until the coverage requirements are fulfilled. These subregions may be refined to create smaller subregions if there are heavy debris layers and coverage requirement cannot be met. Objectives have been achieved through proper simulations of newly introduced Wi-Fi Halow with attenuations of various materials based on the complexity of collapsed structure. Comparison of this work with existing techniques shows the novelty of this idea as Wi-Fi Halow is primarily for IoTs and can lead this work for a better solution in post-disaster rescue.**

***Index Terms*—Wi-Fi radar, Wi-Fi Halow, collapsed structure, coverage, IoT**

I. Introduction

In the modern era of wireless communication, IoTs have witnessed an incredible growth and our lives have become more reliant on these ubiquitous solutions [1]. Recently, wearables, sensors or similar devices that sense or share data through communication medium were considered to be part of IoTs but now focus is being shifted to device free communication [2]. This is primarily because of the application of wireless signals as sensors. The most evident are Wi-Fi signals which are now available almost everywhere. It has been witnessed that these Wi-Fi signals have more role than being sole communication medium for Internet connection [3] [4].

There is an observation that most of the Wi-Fi signal's applications emerge from indoor environments as mostly IoTs are deployed inside buildings; so, there is dire need to have better indoor localization and navigation using these signals for better performance. Channel state information (CSI) [5] output from Wi-Fi signals plays pivotal role for collecting relevant information for any application. Some of these are; breathing detection [6], indoor localization [7], human computer interaction [8], sleep monitoring [9] [10], fall detection [11] and activity recognition [12]. But these applications have much limitations as indoor environments are bit complex in nature. Wireless signals face much obstructions in these environments which causes more attenuations hence weakening the signal penetration. It is because of non-line of sight (NLOS) communication that causes multipath, scattering, reflections and fading [13]. Let us consider breathing detection [6], which is highly dependent on better signal coverage in indoor environments. It is very useful application as it can revolutionize the health sector and can also be prominent solution in post-disaster rescue. But unfortunately, it is limited to simple indoor scenarios and cannot work for complex environments like collapsed structures.

Subsequently, nature of collapsed structure and its constituents are major hurdle towards application of breathing detection using Wi-Fi signals. It is because of the multi-object scenario encountered to signals as normal structure after collapse results into many pieces laying over each other by forming layers of debris. This causes more signal distortion and fading eventually damping it in the debris [14]. Yet, there is dire need to have better signal coverage in collapsed structures as it can lead to post-disaster rescue. The most promising idea behind the realization of Wi-Fi radar for a collapsed structure is lack of technology in developing countries where mostly collapses occur and results in huge human losses. It is also because of the fact that existing solutions are much costly, non-ubiquitous and non-available in the most part of the world. So, motivated by this, the goal of our work is to have deep research on the coverage of Wi-Fi signals. This work does not provide the post-disaster rescue but it essentially paves way for further research in this domain.

The main idea of this work is to study the coverage of Wi-Fi signals in collapsed environments. In order to achieve this goal, we figure out the most common type of debris found in developing countries. There is need to conduct an extensive field survey of earthquake hit area to realize this objective. Afterwards, we employ an echo model that uses Wi-Fi radar approach to receive reflected signals from debris which contains proper CSI. Authors also proposed a Wi-Fi radar technique for collapsed structures in [15]. Subsequently, selection of Wi-Fi frequency which may provide better result is also another important aspect. Traditionally, Wi-Fi was being operated at 5GHz and 2.4GHz but recently, Wi-Fi Halow [16]

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operating at 900MHz had been proposed. Since, it is operating at sub 1GHz, so, it has relatively better coverage than aforementioned bands. It has been primarily designed for IoTs having better signal penetration in cluttered environments. That is why, we also employ sub 1GHz for our Wi-Fi radar approach.

We consider a debris model constituent of brick 10.5˝and concrete 8˝materials from an earthquake scenario. In order to study coverage, radar range equation and path loss models have been modified to work well for our proposed Wi-Fi radar approach. It is assumed that transmitter continuously sends pulses in a directional manner to debris. These signals try to penetrate through the ruin and face attenuations due to complexity of materials and layout of structure leading to damping of signal. Range can be calculated from received signal above than a predefined threshold to have better CSI. If the whole debris is not covered by this approach, we divide the site into subregions based on signal coverage for horizontal layers. It is to be noted that debris has both horizontal and vertical layers. Furthermore, if there are heavy debris layers; it results in more subregions. This partition provide insight about right placement of Wi-Fi radar to have better coverage which can lead us to significant results in future.

The main contributions of this paper are:

- We present Wi-Fi radar coverage models to address the losses and attenuations encountered to Wi-Fi signals for an earthquake scenario. We conducted survey of real disaster site case to map into theory.
- We propose a placement scheme for Wi-Fi radar to have better coverage in collapsed structures.
- We simulate our proposed scheme at Wi-Fi Halow (sub 1GHz). So, this work provides insight on the application of sub 1GHz.
- Finally, we validate our models through simulations for low power. This essentially put emphasis on ubiquitous and low power IoTs for complex structures.

The remainder of paper is organized as follows: Section II provides more related work whereas in Section III, we present coverage models needed for Wi-Fi radar. We formulate and discuss placement models for Wi-Fi radar in Section IV. Simulation results have been provided in Section V. Finally, Section VI concludes the paper.

II. Background and Related Work

In this section, we provide background and relevant work to have better understanding for our research problem. Firstly, we discuss the complexity of problem. This includes behavior of wireless signals for debris scenario. Thereafter, existing tools and techniques for rescue have been presented. Finally, we discuss some techniques from adjoining areas which can be used for disaster case. At the end, we provide our problem statement by considering background and related work.

Wireless signals are adversely affected in complex indoor environments. It becomes even worse in case of collapsed structures as there are multiple layers of debris which causes more reflections, attenuations, fading and other related issues [14]. Although, there is literature which investigate the behavior of radio signals for debris scenario but presented techniques are not much successful and cannot be termed as ubiquitous. A study was conducted by DiCarlofelice and E. DiGiampaolo [17] for an historic town,“LAquila”which was severely hit by an earthquake. Similarly, a study was conducted for various radio bands [50MHz, 150MHz, 225MHz, 450MHz, 900MHz, 1.8GHz] by [14]. There are also some studies on structural health monitoring such as [18] [19] [20] [21] that provide insight about applications of wireless sensors for complex structures.

Now, let us discuss the existing techniques and approaches that make use of wireless signals for possible rescue under collapsed environment [13]. These are wireless sensors [22] and radars [23]. Both techniques have their own advantages but radar based sensing is more preferred as it can provide deep penetration through dielectric barriers. The most famous approaches radar types for rescue operations are IR-UWB radars [24], Ultra-wideband (UWB) radars [25], Continuous Wave Stepped Frequency (CW-SF) Ground penetrating radar [26] and Doppler radars [23]. But these radar technologies are not favorable because cost and availability in developing countries is a big issue.

The most important task to deal with fading and attenuations under debris is to study the path loss models. Although, there is enough literature for path losses encountered to signal for indoor and outdoor environments, yet there are very few works for debris scenario like [27]. There is a survey comprising of path loss models spanning over period of 60 years in [13]. These works provide us insight how can we map path losses in collapsed structures.

In a nutshell, we observe that wireless signal is highly affected in collapsed structures. There is also inference that most of the rescue solutions are mainly based on radars and cannot be regarded as ubiquitous. The cost and availability is also an important criteria for better solution where current solutions does not fit well. According to our study, there is no solution based on application of Wi-Fi signals as sensors for possible rescue. So, this work put emphasis on the most important problem of coverage which Wi-Fi signal encounter in collapsed environments.

III. Wi-Fi Radar Coverage Models

In this section, we discuss coverage models for Wi-Fi radar. Initially, we present debris model where we discuss our field survey to realize the nature of collapsed environment. Afterwards, Wi-Fi radar signal model provides further detail for behavior of wireless signals . Finally, we discuss our placement model for Wi-Fi radar to have better coverage in debris.

A. Debris Model

Let us discuss the nature of debris from our field survey. We conducted this study for Yingxiu, which was epic center of May 12, 2008 earthquake in Sichuan province of China[1].

[1]https://en.wikipedia.org/wiki/Yingxiu

(a) Yingxiu town in maps (b) Xuankou middle school (c) Structural materials

Fig. 1: Yingxiu town, Wenchuan County, Sichuan, P.R. China

It is located in southern Wenchuan county with coordinates of 31°03´32´´N and 103°29´41´´E respectively as shown in Fig 1a. This city was almost completely destroyed by devastating earthquake moment magnitude of 7.9 that hit Sichuan Province on May 12, 2008[2]. We thoroughly investigated the causes of structural collapse from remains of Xuankou Middle School, located in Yingxiu as shown in Fig 1b. It was observed that the most of construction was constituent of brick and concrete structure as shown in Fig 1c. School building did not meet the design requirements for strong columns and weak beams, and the steel banding in the core area was also below the required specification. So, in short, selection of right debris is pivotal to have better coverage. As discussed earlier, we merely study the behavior of concrete and brick materials only. These materials will turn up into multiple objects after an earthquake as shown in Fig 1c.

In order to map observed ruin to theory, we present a debris model as shown in Fig 2b. It shows a model site constituent of brick and concrete spreading over certain area termed as measurement. It can be observed from model that there are layers of materials laying over each other. These layers are much important to be considered as signal is highly affected on each of them. Additionally, we define layer models to further simply the problem. Since it is an established phenomenon that debris layers can be horizontal and vertical but the most important are erect ones which define the depth of ruin. The Wi-Fi signal penetration for both cases will be same as it is more dependent on obstructions in the path rather than direction. Simple and complex layer scenarios are modeled in Fig 3 respectively. Higher number of layers will add more attenuation eventually weakening the signal further.

B. Wi-Fi Radar Signal Model

It is an established fact that indoor environments are relatively complex in nature. This is because of multiple objects scenario such as, walls, halls, doors etc. So, it justifies the idea that wireless signal face much attenuations and become very weak in these environments. Now, let us consider a bit more complex scenario i.e., collapsed structure. If we consider signal penetration to this structure, it can be found that signal behaves worse. But still there is need of investigation for this particular structural layout as it can lead to many rescue solutions in future.

In order to have better understanding for poor behavior of Wi-Fi signal, we consider a simple collapsed environment from our field survey as shown in Fig 1c. It consists of concrete and brick materials only. It also has multiple layers. By layers, we assume the material objects laying over each other either vertically or horizontally. Subsequently, there is need to map Wi-Fi signal for this complex layout. Let us consider the transmission of Wi-Fi signal similar to that of radar, where echo contains useful information. Since, our goal is to discuss the feasibility of Wi-Fi signal for any possible rescue application in future, we apply this Wi-Fi radar approach as shown in Fig 2a . It is assumed that echo signal should be above than a predefined minimum threshold to ensure quality reception.

C. Placement Model

Finally, we discuss our placement model. It is based on the coverage of Wi-Fi radar. We divide whole debris site into subregions as shown in Fig 3. Each subregion can have minimum and maximum layered scenarios. We define the complexity of placement on the basis of layered approach in each subregion. Minimum layers will result in lower subregions in comparison with max ones. In short, the goal of this work is to find the coverage of Wi-Fi signal in collapsed structure which may provide us desired echo. It is dependent on various factors; such as transmitter intensities, frequency band, antenna gains, minimum detectable signal and modeled debris site. We estimate the coverage for our site measurement on aforementioned criteria and propose a placement scheme which can provide better echo.

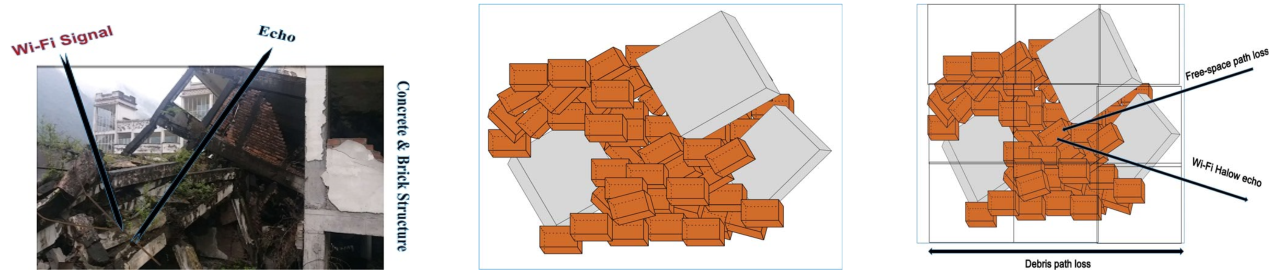
IV. Wi-Fi Radar Placement

In this section, we propose our approach for coverage computation of echo. It is divided into two parts; the first one is about the coverage distance of Wi-Fi signal in collapsed structure whereas second deals with the possible placement of our proposed Wi-Fi radar.

A. Wi-Fi Radar Range

In order to address the coverage issue in collapsed structures, we make use of echo that works on radar principle [28]

[2]https://earthquake.usgs.gov/earthquakes/eventpage/usp000g650#executive



(a) Wi-Fi radar signal model (b) Wi-Fi radar debris model (c) Wi-Fi radar path losses

Fig. 2: Wi-Fi radar coverage modeling on ruins of Xuankou middle school, Yingxiu

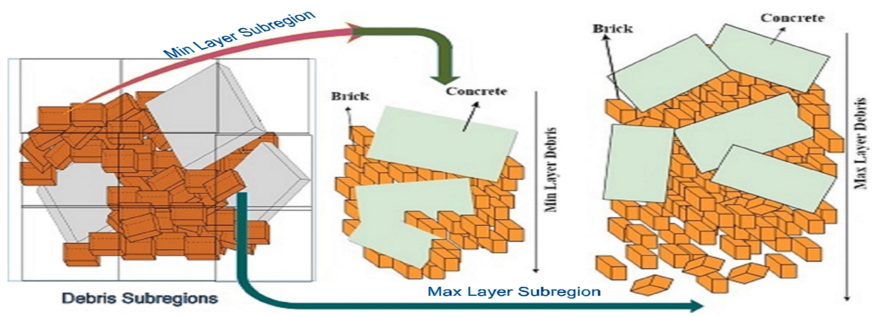


Fig. 3: Illustration of subregion formation with layered approach

known as Wi-Fi radar as shown in Fig 2a. Under normal condition, Wi-Fi transmitter radiates pulses simultaneously which may take various paths. But to simplify the approach, we assume directional pattern of antenna as it can assist for avoidance of multiple aliased signals reflected from unwanted sources. It is also assumed that Wi-Fi radar is placed outside of debris to map it like a practical case.

Let us consider the two-way radar equation to drive the range of our proposed Wi-Fi radar. It is dependent on antenna gains, signal intensities, cross sectional area and distance under normal scenario. It is given as follows;

$$P_r = \frac{P_t G_t G_r \lambda^2 \sigma}{(4\pi)^3 R^4} \tag{1}$$

where P_t and P_r are transmit and received power, whereas G_t and G_r are corresponding antenna gains respectively. σ is cross sectional area which in our case is debris area while R and f denotes the range and frequency, respectively. Now, in order to find returned signal from debris, we first consider signal at ruin site followed by signal reflected from debris. By modifying (1) and with selection of radar cross sectional area as $G_r = \frac{4\pi\sigma}{\lambda^2}$ which in our case is debris site, we get received signal at the input of Wi-Fi radar as;

$$\begin{Bmatrix} Received\,Signal \\ at\,WiFi\,radar \end{Bmatrix} = \frac{P_t G_t \lambda^2 4\pi\sigma}{(4\pi R)^2 \lambda^2} \times \frac{G_r \lambda^2}{(4\pi R)^2} \tag{2}$$

On reducing the above equation to log form, we get;

$$\begin{aligned} P_R = P_T + G_T + G_R + 20log(\frac{\lambda}{4\pi R}) \\ + 10log(\frac{4\pi\sigma}{\lambda^2}) + 20log(\frac{\lambda}{4\pi R}) \end{aligned} \tag{3}$$

Let us consider 4^{th} and 6^{th} term of (3). Both of them are same and represent free-space loss in $-\beta_1$ form . So, the only remaining term is 5^{th} which reflects the radar cross section and known as target gain factor. So, (3) can be modified as;

$$P_R = P_T + G_T + G_R + G_\sigma - 2\beta_1 \tag{4}$$

where $\beta_1 = 20log(\frac{4\pi f R}{c})$ and $G_\sigma = 10log(\frac{4\pi\sigma}{\lambda^2})$. Now, (4) provides information about strength of received signal at input of Wi-Fi radar in log form. It also consist of free space path loss factor. But in real scenario, Wi-Fi signal penetration through collapsed structures comprise two path losses as shown in Fig 2c. We assume that signal will firstly travel in free-space before entering into debris. Thereafter, it will travel in cluttered environments causing multi-paths, fading and attenuations. We formulate this assumption as follows;

$$PL = PL_{free-space} + PL_{debris} \tag{5}$$

It can be observed from (4) that free space path loss is already dealt. The only remaining term is PL_{debris}. In order to introduce path loss in debris, we consider X_G. It includes all possible path losses encountered to Wi-Fi signal. It can be formulated with number of layers from selected debris materials along-with the attenuation factor AF these encounter at Wi-Fi Halow frequency. We have considered only brick and concrete scenario as per our site survey. X_G can be formulated as in (6), where m and n refers to number of brick and concrete layers respectively.

$$\begin{aligned} PL_{debris} = X_G = m * AF(Brick\,Layer) \\ + n * AF(Concrete\,Layer) \end{aligned} \tag{6}$$

Now, there is need to incorporate the losses faced by Wi-Fi radar in (4) which will yield the following relation;

$$P_R = P_T + G_T + G_R + G_\sigma - 2\beta_1 - X_G \tag{7}$$

In order to compute coverage, we reconvert log form to ordinary one and make use of (2) which gives us range in power form.

$$R^4 = \frac{P_t G_t G_r}{P_r}(\frac{\lambda^2}{4\pi})(\frac{4\pi\sigma}{\lambda^2})(\frac{\lambda^2}{4\pi})\frac{1}{X_g} \tag{8}$$

Finally, by doing some mathematics, we get following relation for coverage computation with all possible losses from debris.

$$WiFi\,radar\,range = R = \sqrt[4]{\frac{P_t G_t G_r}{P_r}(\frac{\lambda^2\sigma}{(4\pi)^3})\frac{1}{X_g}} \tag{9}$$

(9) provides the complete relation for coverage computation in our considered debris environment. P_t, G_t, G_r, and P_r are known terms of antenna gains power intensities whereas σ denotes the debris area under observation. Under normal conditions, it is $1m^2$. P_r is the minimum detectable signal which can provide us desired echo. It means the strength of received signal which conveys proper information about breathing signals under debris. CSI contains the sensing information and can further help in post-disaster rescue. In order to achieve required echo, the received SNR should be above or equal to a pre-defined threshold given below;

$$SNR \geq SNR_T \tag{10}$$

B. Subregion Formation Algorithm

The basic objective of subregion formation is to estimate the possible placement of Wi-Fi radar to have better coverage for whole debris. Let us consider the debris model as enclosed rectangular area $EnR(B_C)$ shown in Fig 2c. Let H_{EnR} and W_{EnR} be the height and width of this assumed rectangle. Now, in order to partition the debris into subregions, we make use of coverage from single Wi-Fi radar. We also assume that coverage distance by Wi-Fi radar is d_{cov} for partitioning. This gives us initial partition as shown in first section of Fig 3.

Let us first divide the debris model into subregions using initial d_{cov} from minimum layers scenario. This provides an approximation of coverage. In order to have better d_{cov}, we make use of SNR . It should be above than predefined threshold SNR_T, so that echo should contain reliable information which can further be processed for rescue related work in future. Now, let us consider the case of our maximum assumed layers, where there is need to redefine the subregions based on d_{cov}. So, in short, we get a upper and lower bound coverage for Wi-Fi radar. Initial number of subregions is given by $l = 1, 2, 3, ...SRW_E \times SRH_E$. It can be formulated as ;

$$SRW_E = \frac{W_{EnR}}{(\sqrt{2} * d_{cov})} \qquad SRH_E = \frac{H_{EnR}}{(\sqrt{2} * d_{cov})}$$

where $SRW_E \times SRH_E$ gives the maximum number of subregions. Now, in order to compute the height and width of each region, we make use of following relations;

$$Height_{SR} = \frac{H_{EnR}}{SRH_E} \qquad Width_{SR} = \frac{W_{EnR}}{SRW_E}$$

We present subregions formation **Algorithm** as follows;

Algorithm: Subregion Formation Algorithm

Result: d_{cov},SR

Set radius=d_{cov}; W_{EnR}=a; H_{EnR}=b; SRH_E=0; SRW_E=0; SR=0; l=0;

Compute d_{cov};

Compute $SRW_E = \frac{W_{EnR}}{(\sqrt{2} * d_{cov})}$;

Compute $SRH_E = \frac{H_{EnR}}{(\sqrt{2} * d_{cov})}$;

l=l+1;

if *layer==min* **then**
    if $SNR \geq SNR_T$ **then**
        SR=SR+1;
        (Create Less Subregions)
    end
else
    layer==min **if** $SNR \geq SNR_T$ **then**
        SR=SR+n;
        (Create More Subregions)
    end
end

C. Performance Analysis

Let us analyze our proposed placement scheme for Wi-Fi radar in collapsed structures. These environments are very much complex in nature as debris forms multi-layered scenario where Wi-Fi signals is highly affected from attenuations. This is why that the most of rescue operations are manual across the world. Recently, some studies like [23] [17] [26] proposed radar based approaches that make use of wireless signals but could not provide appreciable results. Although, these provided insight about application of wireless signals under debris scenario but still cannot be regarded as ubiquitous. Cost and availability are another factors that motivate to find an alternative.

We formulate Wi-Fi radar to have better echo reception. Then a placement scheme has been proposed similar to [29] which was primarily for small cells. Although, there are many other placement techniques like [30] [31] but none of those deals with Wi-Fi radar and collapsed structure in particular. Similarly, path loss modeling under debris is another challenge for Wi-Fi radar as normal radar based techniques does not consider losses for debris like in [13] [32]. We make use of modified path loss model from [13] [32] which take complex structure into consideration and map it to our proposed Wi-Fi radar approach. So, in brief, our Wi-Fi radar has novelty and its placement scheme also increases the worth of this study.

Limitations: Let us discuss the limitations in proposed placement scheme study. This work is primarily based on simulations which limits its practicality. The envisioned Wi-Fi radar coverage models focus on more theoretical aspect without going into details of derivations of attenuations. The reasons behind these limitations are being the novelty and primitive nature of this study. We cannot deploy the solution in real environment without having proper simulations and continuous improvement in theoretical aspects. We are certain this study can provide break through towards more investigation in this field followed by IoT based implementation.

V. Simulations

In this section, we present simulation method and discuss our results. Most of the simulation parameters are regulated by government agencies or regulatory bodies.

A. Simulation Method

The most important feature to have better results is right selection of simulation parameters. Simulations have been performed on Intel(R) Xeon(R) 3.3GHz CPU, 16GB RAM with MATLAB 17a on 64bit OS with parameters shown in Table I.

TABLE I: Simulation Parameters

Parameter	Values
Operation Frequency	(902, 779)MHz
Transmission Power	(23, 10) dBm
Antenna Gains	(13, 26) dBi
Radar Cross Section	$1m^2$
Modulation Type	256QAM with $R = \frac{5}{6}$
Channel BW at 256QAM	1MHz
SNR Threshold	20dB
Debris Type	Brick, Concrete
Attenuation of Brick 10.5˝	7dB at 900 MHz
Attenuation of Concrete 8˝	23dB at 900 MHz
Debris Site Measurement	10×6
Minimum Debris Layers	10 (8b+2c)
	12 (10b+2c)
Maximum Debris Layers	9 (6b+3c)
	14 (12b+2c)
	8 (4+4)

Normally, Wi-Fi signals operate at three different ISM frequencies. These are 5GHz, 2.4GHz and sub 1GHz. High frequencies does not perform well in complex structure and face much attenuations. Since, our goal is to have better coverage in collapsed structure, so, we consider sub 1GHz. This is also known as Wi-Fi Halow and is specifically designed for cluttered environments where most of the IoTs are used. Most of the countries have their own standards for Wi-Fi Halow as regulated as IEEE Task Group [33]. Since we conducted site survey of an earthquake hit area of China, so, we mainly consider operating frequency of Wi-Fi Halow for US(902MHz) and China(779MHz) as given in [16] [33].

TABLE II: Comparison of Sub-region

Layered Scenario	902MHz(US)	779MHz(China)
Min Layer 10 (8b+2c)	8	2
Min Layer 12 (10b+2c)	54	8
Max Layer 9 (6b+3c)	28	4
Max Layer 8 (4b+4c)	72	15
Max Layer 14 (12b+2c)	252	45

Likewise, antenna gains and transmission power have been selected as per set standards of Federal Communications Commission (FCC)[3], para 17.245 rules for PTMP (Point to multi-point). We consider 23dBm and 10dBm transmission power for US(902MHz) and China(779MHz) respectively. Similarly, antenna gains are 13dBi and 26dBi for selected countries by following the PTMP regulations for Wi-Fi frequencies as given in rules [4].

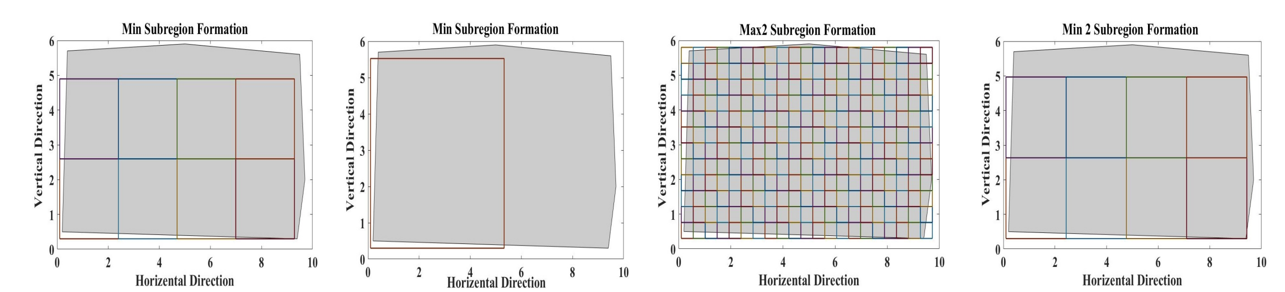
We select brick 10.5˝and concrete 8˝as the constituents of debris model from our field survey. We make use of attenuations caused by these materials from the study provided by Digi [5]. Similarly, various layers have been considered for simulations that define the depth of debris. In order to have better signal reception, SNR threshold is selected to be 20dB which implies that power received at input of Wi-Fi radar should be above than -70dBm. It is possible only with 256QAM case having R=3/5 in 1MHz channel [33].

B. Simulation Results

Simulations have been performed on afore-discussed parameters. The main objective of these simulations is to create subregions out of debris site where Wi-Fi radar can be placed to get maximum coverage for collapsed structures. We considered US and China frequency standards for Wi-Fi Halow. It is because of the fact that our field survey was from Chinese earthquake site and US standard is accepted worldwide. So, comparison can provide significant results. We perform 10 simulations in over-all for different layer scenarios of debris. The results are provided from Fig 4 to Fig 6.

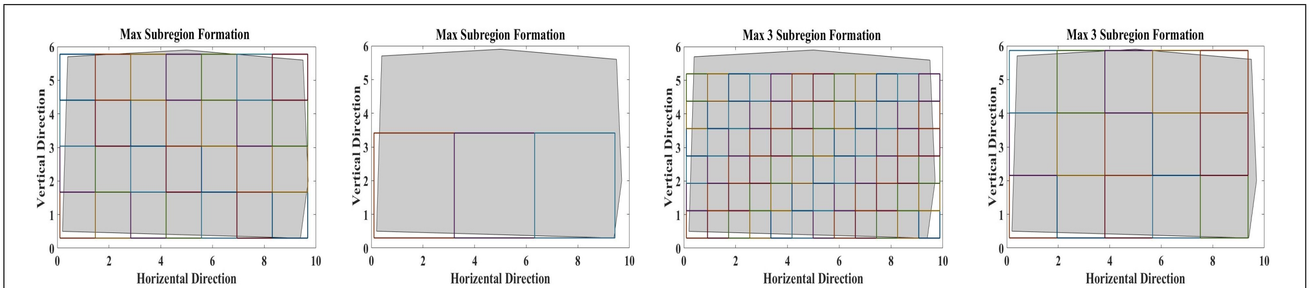
1) Comparison w.r.t Minimum Layer Scenario: Let us compare the simulation results for minimum layer scenario. As discussed earlier, we have two types of materials i-e., brick and concrete. These have unlike attenuation factors. So, layers of brick will have quite different behavior in comparison with concrete layers. Normally, there are more brick layers than concrete one in collapsed structures. Therefore, we consider minimum concrete layers in relation with bricks to have minimum layer debris scenario. There are two scenarios where the first one is 10 layered case comprising 8 brick and 2 concrete pieces and second case consists of 12 layers i-e.,10 brick and 2 concrete pieces. We simulate Wi-Fi Halow signal frequency for both US and China for this minimum layered

[3]https://www.fcc.gov/tags/radio-rules
[4]https://www.air802.com/fcc-rules-and-regulations.html
[5]http://ftp1.digi.com/support/images/XST-AN005a-IndoorPathLoss.pdf



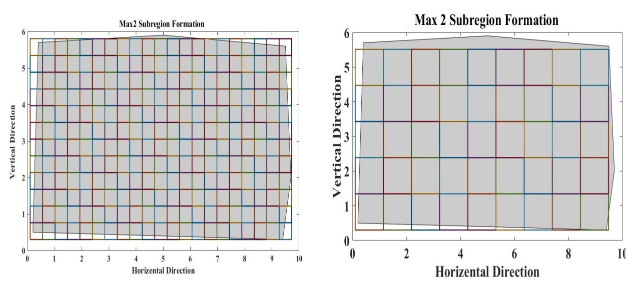
(a) Min Layer (10) US (b) Min Layer (10) CN (c) Min Layer (12) US (d) Min Layer (12) CN

Fig. 4: Minimum layer (10, 12) scenario comparison for US and China



(a) Max Layer (9) US (b) Max Layer (9) CN (c) Max Layer (8) US (d) Max Layer (8) CN

Fig. 5: Maximum Layer (9, 8) scenario comparison for US and China



(a) Max Layer (14) US (b) Max Layer (14) CN

Fig. 6: Maximum Layer (14) scenario comparison for US and China

debris and partition the site into sub regions. Results presented in Fig 4 shows that using low frequency as per Chinese standard, we can get less subregions. These are 8 for US case and 2 for Chinese scenario with 10 layers. Similarly, it is 54 and 8 sub-regions for US and China respectively in 12 layered case as presented in Table II.

2) Comparison w.r.t Maximum Layer Scenario: Finally, we compare the simulation results for maximum layered debris as per our proposed approach. Number of concrete layers define the max layer scenario. It is because of higher attenuation factor of concrete materials. So, we have considered three cases i-e., 9 layered (6 brick, 3 concrete), 14 layered (12 brick, 2 concrete) and 8 layered (4 brick , 4 concrete) as shown in Fig 5 and 6 . All of these provide results in different number of subregions but better performance of Wi-Fi Halow for Chinese scenario remains intact. It can be observed from Table II that we get less sub-regions while operating at 779MHz. The comparison also ensures that Wi-Fi Halow as per FCC standard allows creation of 5 or higher times number of subregions.

VI. Conclusion

In this study, we investigated the coverage issue of Wi-Fi signals for collapsed structures. In order to meet our objective, we proposed placement scheme using Wi-Fi radar by making use of debris model formed in the light of field survey of an earthquake hit area. We compared performance of Wi-Fi radar while employing various standards and also cross-verified with existing literature. As a conclusion, it was figured out that our proposed placement can play a vital role in better coverage for Wi-Fi signals which can further be used for rescue efforts in future. It also emphasis on the ubiquitous post-disaster rescue as our opted Wi-Fi Halow has been primarily designed for IoTs. So, in short, we can expect IoT based rescue solution in future.

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References

[1] J. Lin, W. Yu, N. Zhang, X. Yang, H. Zhang, and W. Zhao, "A survey on internet of things: Architecture, enabling technologies, security and privacy, and applications," *IEEE Internet of Things Journal*, vol. 4, no. 5, pp. 1125–1142, Oct. 2017.

[2] P. J. Soh, G. A. Vandenbosch, M. Mercuri, and D. M.-P. Schreurs, "Wearable wireless health monitoring: Current developments, challenges, and future trends," *IEEE Microwave Magazine*, vol. 16, no. 4, pp. 55–70, May 2015.

[3] M. F. Khan, G. Wang, M. Z. A. Bhuiyan, and X. Li, "Wi-Fi signal coverage distance estimation in collapsed structures," in *Proceedings of IEEE International Symposium on Parallel and Distributed Processing with Applications and 2017 IEEE International Conference on Ubiquitous Computing and Communications (ISPA/IUCC)*, Dec. 2017, pp. 1066–1073.

[4] Z. Zhou, C. Wu, Z. Yang, and Y. Liu, "Sensorless sensing with Wi-Fi," *Tsinghua Science and Technology*, vol. 20, no. 1, pp. 1–6, Feb 2015.

[5] Y. Hu and A. Ribeiro, "Optimal wireless communications with imperfect channel state information," *IEEE Transactions on Signal Processing*, vol. 61, no. 11, pp. 2751–2766, Jun. 2013.

[6] X. Liu, J. Cao, S. Tang, J. Wen, and P. Guo, "Contactless respiration monitoring via off-the-shelf Wi-Fi devices," *IEEE Transactions on Mobile Computing*, vol. 15, no. 10, pp. 2466–2479, Oct 2016.

[7] L. Gui, M. Yang, H. Yu, J. Li, F. Shu, and F. Xiao, "A cramer–rao lower bound of CSI-based indoor localization," *IEEE Transactions on Vehicular Technology*, vol. 67, no. 3, pp. 2814–2818, Mar 2018.

[8] K. Ali, A. X. Liu, W. Wang, and M. Shahzad, "Keystroke recognition using Wi-Fi signals," in *Proceedings of the 21st Annual International Conference on Mobile Computing and Networking - MobiCom '15*, Sep. 2015, pp. 90–102.

[9] F. Li, C. Xu, Y. Liu, Y. Zhang, Z. Li, K. Sharif, and Y. Wang, "Mosleep: Unobtrusive sleep and movement monitoring via Wi-Fi signal," in *Proceedings of IEEE 35th International Performance Computing and Communications Conference (IPCCC)*, Dec. 2016, pp. 1–8.

[10] L. Li, W. Yang, M. Z. A. Bhuiyan, and G. Wang, "Unsupervised learning of indoor localization based on received signal strength," *Wireless Communications and Mobile Computing*, vol. 16, no. 15, pp. 2225–2237, May 2016.

[11] H. Wang, D. Zhang, Y. Wang, J. Ma, Y. Wang, and S. Li, "RT-Fall: A real-time and contactless fall detection system with commodity Wi-Fi devices," *IEEE Transactions on Mobile Computing*, vol. 16, no. 2, pp. 511–526, Feb. 2017.

[12] Q. Chen, B. Tan, K. Chetty, and K. Woodbridge, "Activity recognition based on micro-doppler signature with in-home Wi-Fi," in *Proceedings of IEEE 18th International Conference on e-Health Networking, Applications and Services (Healthcom)*, Sep. 2016, pp. 1–6.

[13] C. Phillips, D. Sicker, and D. Grunwald, "A survey of wireless path loss prediction and coverage mapping methods," *IEEE Communications Surveys Tutorials*, vol. 15, no. 1, pp. 255–270, First 2013.

[14] C. L. Holloway, G. Koepke, D. Camell, W. F. Young, and K. A. Remley, "Propagation measurements before, during, and after the collapse of three large public buildings," *IEEE Antennas and Propagation Magazine*, vol. 56, no. 3, pp. 16–36, June 2014.

[15] M. Z. A. B. Muhammad Faizan Khan, Guojun Wang and X. Xing, "Towards Wi-Fi radar in collapsed structures," in *Proceedings of IEEE SmartWorld, Ubiquitous Intelligence & Computing, Advanced & Trusted Computing, Scalable Computing & Communications, Cloud & Big Data Computing, Internet of People and Smart City Innovations*, Oct. 2018, pp. 664–670.

[16] S. Aust, R. V. Prasad, and I. G. M. M. Niemegeers, "Outdoor long-range WLANs: A lesson for IEEE 802.11ah," *IEEE Communications Surveys Tutorials*, vol. 17, no. 3, pp. 1761–1775, May 2015.

[17] A. DiCarlofelice, E. DiGiampaolo, M. Feliziani, and P. Tognolatti, "Experimental characterization of electromagnetic propagation under rubble of a historic town after disaster," *IEEE Transactions on Vehicular Technology*, vol. 64, no. 6, pp. 2288–2296, June 2015.

[18] M. Z. A. Bhuiyan, G. Wang, J. Wu, J. Cao, X. Liu, and T. Wang, "Dependable structural health monitoring using wireless sensor networks," *IEEE Transactions on Dependable and Secure Computing*, vol. 14, no. 4, pp. 363–376, July 2017.

[19] M. Z. A. Bhuiyan, J. Wu, G. Wang, Z. Chen, J. Chen, and T. Wang, "Quality-guaranteed event-sensitive data collection and monitoring in vibration sensor networks," *IEEE Transactions on Industrial Informatics*, vol. 13, no. 2, pp. 572–583, April 2017.

[20] M. Z. A. Bhuiyan, J. Wu, G. Wang, T. Wang, and M. M. Hassan, "e-sampling: Event-sensitive autonomous adaptive sensing and low-cost monitoring in networked sensing systems," *ACM Transactions on Autonomous and Adaptive Systems*, vol. 12, no. 1, pp. 1–29, Mar. 2017.

[21] M. Arif, G. Wang, and V. E. Balas, "Secure vanets: Trusted communication scheme between vehicles and infrastructure based on fog computing," *Studies in Informatics and Control*, vol. 27, no. 2, pp. 235–246, 2018.

[22] J. Wang, Z. Cheng, L. Jing, and T. Yoshida, "Design of a 3D localization method for searching survivors after an earthquake based on WSN," in *Proceedings of 3rd International Conference on Awareness Science and Technology (iCAST)*, Sept 2011, pp. 221–226.

[23] L. Crocco and V. Ferrara, "A review on ground penetrating radar technology for the detection of buried or trapped victims," in *Proceedings of International Conference on Collaboration Technologies and Systems (CTS)*, May 2014, pp. 535–540.

[24] Z. Li, H. Lv, Y. Zhang, G. Lu, S. Li, X. Jing, and J. Wang, "Detection of trapped survivors using 270/400 MHz dual-frequency IR-UWB radar based on time division multiplexing," in *Proceedings of IEEE Topical Conference on Biomedical Wireless Technologies, Networks, and Sensing Systems (BioWireleSS)*, Jan 2014, pp. 31–33.

[25] J. Li, L. Liu, Z. Zeng, and F. Liu, "Advanced signal processing for vital sign extraction with applications in uwb radar detection of trapped victims in complex environments," *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 7, no. 3, pp. 783–791, March 2014.

[26] G. Grazzini, M. Pieraccini, F. Parrini, A. Spinetti, G. Macaluso, D. Dei, and C. Atzeni, "An ultra-wideband high-dynamic range gpr for detecting buried people after collapse of buildings," in *Proceedings of the XIII Internarional Conference on Ground Penetrating Radar*, June 2010, pp. 1–6.

[27] L. Chen, M. Loschonsky, and L. M. Reindl, "Large-scale fading model for mobile communications in disaster and salvage scenarios," in *Proceedings of International Conference on Wireless Communications Signal Processing (WCSP)*, Oct 2010, pp. 1–5.

[28] S. Henriksen, "Radar-range equation," *Proceedings of the IEEE*, vol. 63, no. 5, pp. 813–814, May 1975.

[29] M. F. Khan and B. Wang, "Effective placement of femtocell base stations in commercial buildings," in *Proceedings of 6th International Conference on Ubiquitous and Future Networks (ICUFN)*, July 2014, pp. 176–180.

[30] G. Chi and D. Wang, "Sensor placement for fault isolability based on bond graphs," *IEEE Transactions on Automatic Control*, vol. 60, no. 11, pp. 3041–3046, Nov. 2015.

[31] P. Chen, C. Qi, and L. Wu, "Antenna placement optimisation for compressed sensing-based distributed MIMO radar," *IET Radar, Sonar & Navigation*, vol. 11, no. 2, pp. 285–293, Feb. 2017.

[32] S. Y. Seidel and T. S. Rappaport, "914 MHz path loss prediction models for indoor wireless communications in multifloored buildings," *IEEE Transactions on Antennas and Propagation*, vol. 40, no. 2, pp. 207–217, Feb 1992.

[33] "IEEE Draft Standard for Information Technology - Telecommunications and Information Exchange Between Systems - Local and Metropolitan Area Networks - Specific Requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Amendment- Sub 1 GHz License-Exempt Operation," *IEEE P802.11ah/D2.0, June 2014*, pp. 1–582, April 2014.