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Wi-Fi Signal Coverage Distance Estimation in Collapsed Structures

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***Abstract*—Recently, there is an increasing trend of research in leveraging Wi-Fi signatures for various applications. This paper investigates the feasibility of effective Wi-Fi signals coverage in the case of collapsed structures. The objectives of this paper are to first identify the possible collapsed structure environments and then to compute the effective distance coverage for license free ISM bands signals to have maximum coverage. This scheme discusses Wi-Fi signals behavior at three different frequencies i.e., 5GHz, 2.4GHz and 900MHz which is also termed as Wi-Fi Halow. We have employed modified path loss model termed as PL-Collapsed for proper reception of echo that estimates the coverage range based on path losses encountered to Wi-Fi signal in these collapsed environments. The objectives have been achieved through proper simulations with different attenuation factors based on complexity of collapsed structure and are compared for aforementioned frequencies. Comparison of simulation results shows that Wi-Fi halow outperforms other frequencies and can be very effective for post-disaster rescue while replacing the traditional Doppler radar techniques hence paving way for more ubiquitous systems.**

***Index Terms*—collapsed structure, Wi-Fi, coverage distance, path loss, IoT**

I. Introduction

With the rapid development of wireless networks, our daily lives are becoming more dependent on these ubiquitous systems and their importance cannot be underestimated. Advent of modern technologies has substantiated that Wi-Fi signals have more role than sole communication medium particularly for indoor environments. Within the indoor environments, wireless signals propagate through direct paths or multiple reflection and scattering paths which outcomes in multiple aliased signals superposing at receiving end [1]. As the wireless signals passes through these physical spaces, they convey information that typifies the environment. These physical spaces may include objects (furniture and walls etc) and humans as well [1] [2] [3].

The indoor environments can be very complex in nature. Researchers have much focused on signal propagation in indoor environments as in [1] [4] because of global positioning system which does not work accurately for indoors scenarios. But there has been very little work done for collapsed indoor environments where there is need of rescuing the lives. Although, some researchers have successfully used wireless signals through Doppler radar or UWB radar to rescue the lives in post-disaster scenario but there has not been any approach proposed for application of Wi-Fi signals for these scenarios.

It is very important to understand the shielding or attenuation properties of collapsed structures because generally collapsed structures constitute a very complex environment, for which no general model exists [5]. Also, there exists a large variety of possible scenarios as different materials may be involved. The radio propagation strongly depends on the dimensions, shape compression and humidity of debris which are subject to variations [6]. The wireless signal greatly decreases in these environments resulting poor signal reception and endangering the rescue efforts. With the proper prediction of attenuation caused in these complex collapsed scenarios, we can better plan and build futuristic networks that are adaptable for spatiotemporal environments [1] [7].

The main objective of this paper is to evaluate the feasibility of Wi-Fi signals for collapsed structured environment. Wi-Fi or IEEE 802.11 signals refers to unlicensed bands that exist in the world for industrial, scientific and medical devices; these bands are termed as unlicensed ISM bands and these are 5GHz and 2.4GHz frequency bands [8]. Couple of years ago, IEEE802.11ah has been proposed which operates at 900MHz band [9]. We have investigated the wireless signal propagation at Wi-Fi bands for collapsed structures. These signals are badly affected from attenuation because of higher frequencies as compared to work done by [10] where signal has been propagated at 434MHz. We envisaged the path losses and estimated the coverage distance. This coverage distance ensures the proper signal reception at receiver side which in turn can be used for rescue efforts.

In this paper, we present a comprehensive model PL-Collapsed for path losses in collapsed structures which ensures the estimation of coverage distance. In this model, we have considered brick wall collapsed structure which has more obstacles than normal indoor environments. It is assumed that Wi-Fi transmitter is located outside of the collapsed structure. It continuously sends the signals like Doppler radar. These continuous signals pass through the debris and reflects backs to receiver after facing so many obstacles which weakens them. The nature of obstacles in the debris defines the attenuation and path losses faced by signal. We have modelled three types of brick wall based on the thickness of brick i.e., 3.5″, 7″and 10.5″which after collapse causes different path losses. We have also considered minimum detectable signal strength that ensures the quality of echo because it contains all required information for rescue. At the end, we compare

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the coverage distances of these Wi-Fi frequencies to predict the best frequency band for collapsed structures.

The main contributions of this paper are;

- We define a model termed as PL-Collapsed for path losses and coverage estimation in collapsed structured environments.
- We have simulated Wi-Fi signals penetration in collapsed structures which is first work in this domain.
- Finally, we validate PL-Collapsed for Wi-Fi frequencies and compare the simulation results which provides immense insight about application of Wi-Fi Halow for collapsed structures. This work also paves way for internet of things for post-disaster scenarios as Wi-Fi halow is primarily for IoTs.

The remainder of paper is organized as follows: Section II provides the background and related work whereas Section III describes problem definition. We discuss our proposed model PL-Collapsed in Section IV. Section V presents simulation results. Section VI completely analyzes the work and compare it prior works. Finally, Section VII concludes the paper.

II. Background and Related Work

This section provides background of the problem. We first present some related work on the significance of wireless signals in collapsed structures and then existing techniques have been discussed. Furthermore, literature related to path loss modelling for various frequencies has been presented with some room of improvement which we have focused for our research.

The fundamental challenge of communication in the collapsed structure is higher attenuation of wireless signals caused by scattering and losses in the debris [5]. Human activity detection under debris is a topic of significance for earthquake survivor detection. Several tools and technologies exists for this type of detection such as high sensitivity microphones, micro-cameras, sensors, radars, and so on. Some of these tools have low penetration and high susceptibility to external noises [11]. A WSN based approach was proposed in [12] [13] [14] and [15].

The most preferred technique is radar based sensing as they have the ability to penetrate deep through dielectric barriers. Doppler radars are used for recognition of life signals by spotting micro-Doppler signatures of human activity such as torso bending, breathing and arm swinging [16] [17]. The operation principle applied is the detection of phase change of the pulsed wave Doppler when echo is received from human heart. Additive White Gaussian Noise (AWGN) channel model along with fading has been used in [18] to compute the noise power and losses. Similarly, based on Doppler effect, an ultra-sensitive compact portable microwave life-detection device has been introduced and implemented while operating at 1.15GHz center frequency in [19]. Another such case to use wireless signals is Ultra-wideband(UWB) radar [20]. A dual- frequency IR-UWB radar system was developed in [21] which combines two IR-UWB radars with different center frequencies i.e., 400MHz and 270MHz. Authors of [11] conducted study on use of an Enhanced Ultra Wide Band (UWB), Continuous Wave Stepped Frequency (CW-SF) Ground penetrating radar as rescue equipment.

It is utmost important to identify the possible radio bands which can effectively penetrate into debris. DiCarlofelice and E. DiGiampaolo [6] [10] conducted localization of radio emitters into collapsed buildings after earthquake. A measurement campaign was carried out in a typical European historical city, LAquila, which was stroke by a severe earthquake. Similar research was carried by [5] for 50 MHz, 150MHz, 225MHz, 450MHz, 900MHz, and 1.8GHz.

Path loss modelling is an important parameter for wireless signal coverage in collapsed structures. A thorough survey of path loss prediction methods, spanning more than 60 years of fairly continuous research has been presented in [1] [22] [23]. Path loss models for complex environments was firstly proposed by Rappaport [4]. Since then, signals attenuations in indoors and outdoors has been tested by many researchers. The UWB indoor channel behavior over the band 3.6 to 6GHz was focused by Durantini [24]. Empirical models for 5.3GHz and 5.85GHz radio propagation path loss in and around residential areas were developed by [25] [26]. Wide range of frequencies i.e., 800MHz to 8GHz band for multi-floored scenario were measured in [27]. Work such as [28] was carried for path loss estimation in higher frequencies i.e., 2.5 and 60GHz. Various studies were conducted for Wi-Fi bands such as [7] and [9]. Outdoor range extension techniques have been applied after proper prediction of path losses as [29].

We observe that current rescue solutions are based on radars and cannot be regarded as ubiquitous. Similarly, the behavior of wireless signal varies with frequencies, i.e., lowering frequency means higher penetration for collapsed structures and converse also follows trend. Existing path loss models only considers complex indoor or outdoor environments but there is no work existing for Wi-Fi signals penetration in collapsed structures which in fact is badly affected because of higher path losses.

III. Problem Definition

This section describes the problem formulation. In this section, we firstly investigate the problem of wireless signal particularly Wi-Fi coverage in collapsed structure and then Wi-Fi signal model has been presented to receive the echo from debris.Thereafter, we propose brick wall and echo model to identify the collapsed structure environment and debris model further elaborates the behavior of Wi-Fi signals for these environments.

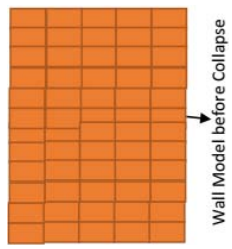
A. Wi-Fi Signal Model

Collapsed structures are very complex like collapsed buildings, halls, houses and workshops etc, and are constituent of materials such as concrete, bricks, metallic, wooden furniture and others. These materials cause more obstacles for wireless signals particularly Wi-Fi signal which is already very weak. So, wireless signals face many obstacles in collapsed structures as compared to normal indoor environments because walls,

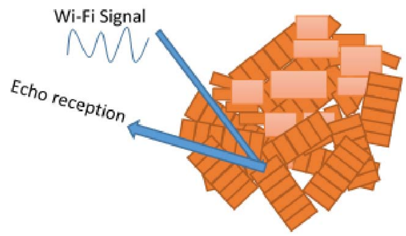
(a) Collapsed Brick Wall

(b) Scattered Collapsed Brick Wall

Fig. 1: Illustration of collapsed brick wall scenarios



(a) Brick Wall Model



(b) Echo Mechanism

Fig. 2: Illustration of echo mechanism

buildings and others turn into many pieces making a huge debris which results in high path losses. Higher path losses make it difficult for Wi-Fi signals to have good penetration.

Let us consider a brick wall collapsed structure. The thickness of brick walls and pieces which it forms after collapse defines the complexity of problem. Fig 1a shows the complex collapsed wall structure as it has more thickness and layers than Fig 1b which has more pieces but less layers. Here by layers we mean that pieces laying on each other after the collapse causing multi object scenario. So, when the Wi-Fi signal will be transmitted into debris, it will face more obstructions.

We consider Doppler radar approach to estimate the range of wireless signal. When an antenna radiates its signal simultaneously, the signal can take many paths to the receiver. Each path may interact with the environment in a chaotically different way and causes delay spread as well as multipath fading. These collapsed environments causes every possible fading types whether its slow-fading, shadowing, large-scale fading, scattering, fast fading or small scale fading. These fading factors weakens the signals particularly Wi-Fi signals that is already very weak to pass through these obstacles.So, we have assumed that antenna used is directional one to avoid any interference from other sides because this received signal from collapsed structure can be used in rescue and interference can distort it.

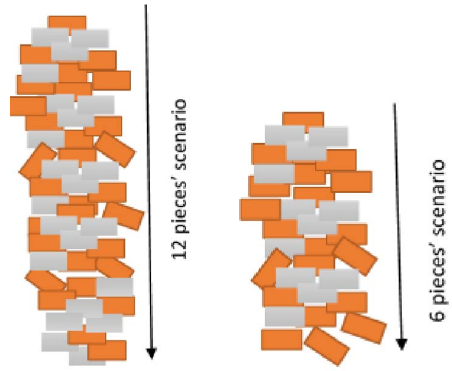
B. Brick Wall and Echo Model

In order to simply the problem, we have considered brick wall for Wi-Fi distance coverage estimation. Brick walls may have different attenuation factors based on the way these are constructed. In other words, it means thickness of wall. We have assumed it to be 3.5˝, 7˝and 10.5˝.Generally, brick wall before collapse is like model presented in Fig 2a. Under normal conditions, Wi-Fi signal can easily penetrate through this type of wall structure but after collapse; the debris caused because of this wall creates more obstacles for signal. Attenuation depends on number of obstacles as well as their thickness like 10.5 ˝brick wall collapse will have more attenuation than brick 3.5˝.

The basic idea of this model is same as Doppler radar principle to send the Wi-Fi signal to the debris which firstly will travel in free space before penetrating into debris.It will collide with multiple objects and will either scatter, reflect and damp. We require wireless signal to be reflected back to the receiver in the form of echo as shown in Fig 2b, which can then further be used for estimation of coverage distance.Range of wireless signal is assumed to be half of total coverage distance in order to have significant information in the echo.

C. Debris Model

In order to estimate the coverage distance, we have assumed a particular model of debris which is formed after the collapse of brick wall which may have several layers. These layers refer to vertical alignment of brick on each other. Each layer causes fading factors and weakens the signals. So, to generalize the solution, we have considered that debris can have minimum six layer or twelve layers for worst case attenuation as shown in Fig 3a and 3b. If the layers are less than six, signals do not encounter much penetration loss. In real environments, there can be 5 layers at one place and 12 layers on next place because it is random distribution caused by wall collapse. So,



(a) 12 layered debris scenario (b) 6 layered debris scenario

Fig. 3: Illustration of layered approach for debris.

wireless signal penetration will vary from point to point in debris. We have only focused vertical layered approach in this work. Horizontal layers also behave same if transmitter sends signal horizontally because directional antenna has been considered. We have also considered the minimum detectable signal(MDS) for a given radio which can ensure quality reception of echo. This can be a function of the acceptable error rate: MDS(Pe), where Pe is the probability of bit error.

Our problem is to find coverage distance (that may provide us desired echo for rescue) in collapsed structure based on this minimum detectable signal threshold. This coverage distance varies at different frequencies. So, we have to simulate it across all Wi-Fi operating frequencies and compare the results in order to know the trend. At the end, we have to analyze the best operating frequency for collapsed structure and discuss its feasibility.

IV. PL-Collapsed: Proposed Approach

In this section, we present PL-Collapsed model. It includes the geometry of transceivers as well as path loss modelling in collapsed structures. This model takes echo and debris models into consideration as well in order to effectively compute the coverage distance for Wi-Fi signals.

The basic idea of this approach is to compute coverage distance from path losses incurred in collapsed structure. So, path loss computation provides insight about the losses encountered to wireless signal. These losses weaken the signal eventually damping it. We assume that Wi-Fi transmitter sends the continuously which strikes multiple objects in the collapsed structure and reflect back to the receiver as shown in Fig 2b. The receiver can then further apply algorithms to identify potential signals as per requirement but signal reception at receiver is out of the scope of this paper. This work mainly deals with the estimation of coverage distance from where we can have desired echo.

The geometry and placement of the Wi-Fi transmitter and receiver antennas accentuates on signals arriving there from various directions. Omni-directional antennas send and receive signals from all direction whereas directional antennas deal only in a specific direction. In the case of collapsed structure environments, it is preferable to use directional antennas to avoid possible interference and clutter from outside of collapsed structure.

The entire radio link which is much affected from attenuations in collapsed environments can be summarized through link budget equation that is commonly in log-domain form as below:

$$P_{rx} = P_{tx} + G_{tx} + G_{rx} - PL \quad (1)$$

where P and G being the power and antenna gains for transmitter and receiver respectively. Here PL term includes all possible attenuation due to multiple objects in collapsed environments. This formula defines the attenuation and aggregate gain of multiple competing signals because of multiple paths. This also assumes that radio link is not affected by external factors (i.e., interference from other transmitters if there are and thermal noise). In order to compute the desired echo having required information, it should be equal or above than pre-defined threshold termed as minimum detectable signal (MDS). It can be defined for a given radio as a function of acceptable error rate $MDS(P_e)$ (i.e., probability of acceptable error rate; P_e) can be given as below;

$$P_{tx} + G_{tx} + G_{rx} - PL \geq MDS(P_e) \quad (2)$$

Here P and G terms are known for a given radio link whereas PL is path loss and MDS as minimum detectable signal. Equation 1 and 2 shows that path loss is an important factor that affects the quality of signal.The PL becomes more evident in collapsed structures. We are familiar that path loss increases exponentially with the distance. So, in order to define the PL in these complex environments, let us consider distance dependent path loss model which can be given in log form as below;

$$PL(d)[dB] = PL(d_0)[dB] + 10 * \alpha * \log_{10}(\frac{d}{d_0}) \quad (3)$$

where PL(d) is total path loss and $PL(d_0)$ is free space path loss for d_0.It accounts to path loss for first meter or kilometer depending on the environment. α is path loss exponent which also varies with environments. It is about 2 in free spaces but increases with every possible complex environment. In the worst case scenario, it is 6, where there are cluttered and obstructed paths consisting metallic objects as well. We have considered path loss exponent value as 5 because we are dealing with collapsed brick wall only; so, it is supposed to have no metallic structure here. In order to compute free space path loss for first meter, the following relation can be used;

$$PL(d_0)[dB] = 20\log_{10}(d)+20\log_{10}(f)+\log_{10}(\frac{4\pi}{c})-G_t-G_r \tag{4}$$

In this equation, d and f are distance and operating frequency respectively whereas c is speed of light. Wireless signals have more coverage in free space. Now, in order to incorporate the multiple objects into equation 3, we consider the fadings and attenuations caused by complexity of collapsed environment for which following model is exploited.

$$PL = L_t + L_s + L_{mp} \tag{5}$$

where L_t is the trivial free-space path loss, L_s is the loss due to shadowing from large unmoving obstacles like walls, buildings, and L_{mp} is fading due to destructive interference from multipath effects and small scatterers. For simplicity of problem, we only exploit attenuation factor without going to into modification of statistical models which is out of scope. The equation 3 with addition of possible attenuation will as follows;

$$PL(d)[dB] = P_T - P_R = PL(d_0) + 10 * \alpha * \log_{10}(\frac{d}{d_0}) + X_g \tag{6}$$

X_g is new term introduced here which includes all possible losses. Since we have considered collapsed brick wall structure; so, in our case, X_g can be modelled as;

$$X_g = p * AF(Collapsedbrickwall) + FaF \tag{7}$$

where AF is attenuation factor caused by p pieces of collapsed brick wall. Brick has different value of attenuation factors depending on the thickness as mentioned earlier. The last quantity in above equation is FaF which incorporates all fading factors including slow or fast.

After the computation of total path loss, path loss in debris can be derived as below;

$$PL_{Deb} = PL(d)[dB] - PL(d_0)[dB] \tag{8}$$

Here PL_{Deb} refers to path loss encountered to wireless signal in debris. In order to estimate the distance covered in debris, free space distance may be cancelled out from total path loss as above. Finally, modifying and applying some basic math, the coverage distance formula can be derived as under;

$$d = 10^{(\frac{PL_{Deb}}{\alpha})} \tag{9}$$

This d provides the total distance covered but for effective computation and for proper use in rescue as mentioned earlier the coverage distance is considered half of radius.

V. Simulations

This section discusses the simulation method and provide results. Simulation parameters vary with the environments primarily because of regulatory bodies. We compare simulation results for different Wi-Fi frequencies to identify the best performing band for collapsed structures.

A. Method

Proper selection of simulation parameters is pivotal to have desired results. We have some limitations from regulatory bodies like Wi-Fi signals can operate in particular frequency band. Similarly, antenna gains and transmit power is also regulated by Federal Communications Commission(FCC). So, in order to apply Wi-Fi signals for particular cases, we need to comply with standard rules.Simulations have been performed in MATLAB 16a on 64 bit OS with 16GB RAM and Intel(R) Xeon(R) 3.3 GHz CPU as per below simulations parameters.

The available frequencies for Wi-Fi signals are 5GHz, 2.4GHz and latest 900MHz. 900MHz also termed as Wi-Fi halow has been proposed particularly for cluttered environments to exploit IoTs. Transmission power of Wi-Fi signal has been varied from 30 dBm to 12 dBm and antenna gain is taken as 6dBi for higher transmit power and higher for lower transmit power to comply with FCC rules. Proper selection of debris is also an important aspect. There can be various type of debris depending on its constituent. It can be concrete, brick, metallic, wood, glass and others. At this stage, we have considered debris only caused by collapse of brick wall. Herein, bricks can further be of many sizes having different attenuation factors. We have considered three different most commonly used sizes of bricks in the wall. These are brick 3.5″, brick 7″, and brick 10.5″. Brick having more thickness will cause more distortion in signal. Attenuation factor for bricks increases with increase in frequency as per [4]. It changes from 1dB to 3 dB under normal circumstances but varies between 5dB to 8dB in worst case scenarios.

Collapsed wall turns into many pieces forming vertical and horizontal layers from single to tens scattered on the ground. We have assumed minimum 6 and maximum 12 layers for worst case scenario because if layers are less than 6, the wireless signal will not face many attenuations. These layers are assumed to be vertical alignment of pieces where attenuation is much affected. Minimum detectable signal is another important parameter to be carefully selected. It has been taken as -70dBm for effective coverage and strong detection because signals becomes weaker. Lastly, the fading factor is taken as 25dB to comply with the rules. It may vary from 20 to 30 for cluttered scenarios but for wall based debris, it cannot be more than 25.

B. Results

Simulations have been performed on the aforementioned simulation parameters. Results have shown an increasing trend

Transmit Power (dBm)	Maximum Antenna Gain(dBi)	Brick Structure (3.5”) attenuation (dB)	Range in collapsed Structure (m)	
			With 6 pieces	With 12 pieces
30	6	10	0.3553	0.0224
24	12		0.8140	0.0514
18	18		1.8648	0.1177
15	21		2.8225	0.1781
12	24		4.2720	0.2695

(a) 5GHz with Brick 3.5”

Transmit Power (dBm)	Maximum Antenna Gain(dBi)	Brick Structure (7”) attenuation (dB)	Range in collapsed Structure (m)	
			With 6 pieces	With 12 pieces
30	6	15	0.0893	0.0014
24	12		0.2045	0.0032
18	18		0.4684	0.0074
15	21		0.7090	0.0112
12	24		1.0731	0.0170

(b) 5GHz with Brick 7”

Fig. 4: 5GHz a) and b)

Transmit Power (dBm)	Maximum Antenna Gain(dBi)	Brick Structure (10.5”) attenuation (dB)	Range in collapsed Structure (m)	
			With 6 pieces	With 12 pieces
30	6	21	0.0170	0.00005
24	12		0.0390	0.00011
18	18		0.0893	0.00026
15	21		0.1351	0.00047
12	24		0.2045	0.00061

(a) 5GHz with Brick 10.5”

Transmit Power (dBm)	Maximum Antenna Gain(dBi)	Brick Structure (3.5”) attenuation (dB)	Range in collapsed Structure (m)	
			With 6 pieces	With 12 pieces
30	6	6	1.439	0.274
24	12		3.2971	0.6283
18	18		7.5533	1.4393
15	21		11.432	2.1784
12	24		17.303	3.2971

(b) 2.4GHz with Brick 3.5”

Fig. 5: 5GHz c) and 2.4GHz a)

Transmit Power (dBm)	Maximum Antenna Gain(dBi)	Brick Structure (7”) attenuation (dB)	Range in collapsed Structure (m)	
			With 6 pieces	With 12 pieces
30	6	9	0.6283	0.0523
24	12		1.4393	0.1197
18	18		3.2971	0.2742
15	21		4.9904	0.4151
12	24		7.5533	0.6283

(a) 2.4GHz with Brick 7”

Transmit Power (dBm)	Maximum Antenna Gain(dBi)	Brick Structure (10.5”) attenuation (dB)	Range in collapsed Structure (m)	
			With 6 pieces	With 12 pieces
30	6	14	0.1578	0.0033
24	12		0.3615	0.0076
18	18		0.8282	0.0173
15	21		1.2535	0.0262
12	24		1.8973	0.0396

(b) 2.4GHz with Brick 10.5”

Fig. 6: 2.4GHz b) and c)

Transmit Power (dBm)	Maximum Antenna Gain(dBi)	Brick Structure (3.5”) attenuation (dB)	Range in collapsed Structure (m)	
			With 6 pieces	With 12 pieces
30	6	3.5	4.2476	1.6149
24	12		9.7306	3.6995
18	18		22.2915	8.4750
15	21		33.7396	12.8274
12	24		51.0670	19.4151

(a) 900MHz with Brick 3.5”

Transmit Power (dBm)	Maximum Antenna Gain(dBi)	Brick Structure (7”) attenuation (dB)	Range in collapsed Structure (m)	
			With 6 pieces	With 12 pieces
30	6	5	2.8063	0.7049
24	12		6.4289	1.6149
18	18		14.7279	3.6995
15	21		22.2915	5.5994
12	24		33.7396	8.4750

(b) 900MHz with Brick 7”

Fig. 7: 900MHz a) and b)

Transmit Power (dBm)	Maximum Antenna Gain(dBi)	Brick Structure (10.5") attenuation (dB)	Range in collapsed Structure (m)	
			With 6 pieces	With 12 pieces
30	6	7	1.6149	0.2334
24	12		3.6995	0.5347
18	18		8.4750	1.2250
15	21		12.8274	1.8541
12	24		19.4151	2.8063

Fig. 8: (c) 900MHz with Brick 10.5"

of signal coverage with the lowering of frequency. Simulation results are presented from table 4a to 8. Table 4a to 5a provides the simulation results for 5GHz which is higher operating band for Wi-Fi but faces more attenuation. Table 5b to 6b is about the simulation at 2.4GHz, the most common RF band for indoor environments. Wi-Fi Halow or 900 MHz simulation results are given in table 7a to 8.

First consider a worst case scenario i.e., thick brick wall of 10.5″and having 12 layers after collapse. The coverage distance in this scenario for 5GHz is 0.00005m as shown in table 5a which is far low whereas it is 0.0033m at 2.4GHz as shown in table 6b which is 0.00325m more than distance by 5GHz. Coverage distance at 900MHz for this very complex and layered scenario is 0.2334m, shown in table 8, which is multifold than 5GHz and 2.4GHz. This complex and layered scenario weaken wireless signal coverage. Anyhow Wi-Fi Halow has shown remarkable performance as compared to traditional Wi-Fi bands. Similarly, considering best case scenario where brick wall is having normal thickness i.e., 3.5″, results shows better coverage of Wi-Fi Halow. Best coverage distance at 5GHz for 3.5″brick with 6 layers is 4.2720m, table 4a, whereas for 2.4GHz , it is 17.3037m, table 5b, which shows an increasing trend. Wifi Halow again outperforms other bands here with the maximum coverage distance of 51.0670 as in table 7a. Comparison of all results provides insight to better penetration with increase in frequency which validates the application of Wi-Fi Halow in collapsed structures.

Results have shown effective coverage distance of Wi-Fi Halow but it is very high in table 7a which may seems difficult to achieve in practical situation. It is very high primarily because of brick 3.5″with 6 layers but it gradually decreases to 2.8063m with brick 7″having 12 pieces. In short, this justifies the fact that signal becomes weaker with more obstacles. It also ensures the application of Wi-Fi Halow for collapsed structures as traditional Wi-Fi bands behave very poorly in this complex environment.

VI. Performance Analysis

This section provides brief analysis of our work. We first analyze the complexity of problem and proposed approach. Afterwards, we present importance of our work with existing wireless techniques for collapsed environments. Finally, we identify Wi-Fi Halow as potential solution for Wi-Fi based post disaster rescue in order to move further towards ubiquitous systems.

In this paper, we estimated the Wi-Fi coverage distance for collapsed structure environment. These structures have very complex layout and cause higher path losses. This is why most of the researchers did not focus much to evaluate weak Wi-Fi signals for these environments. Although, radar based approaches at lower frequencies have been proposed for rescue but these are bit costly and not accessible everywhere particularly in developing countries where more collapses occur because of poor planning and construction. Observing the increasing trend of smartphones and Wi-Fi everywhere, we came with this idea to use these Wi-Fi signals for possible rescue. So, firstly, there was need of studying the behavior of wireless signals under debris. Collapsed structures affects the Wi-Fi signals unpredictably very bad. We simulated the brick wall (as pilot scenario) collapsed structure having different thickness level for these frequencies. Simulation have shown an increasing trend of Wi-Fi coverage while lowering the frequencies i.e., Wi-Fi Halow outperforms others.

Results have shown that path loss increases as the frequency increases. Comparison of our work with existing path loss estimation at high and low frequencies highlights importance of Wi-Fi based signal coverage estimation in collapsed structures. C. R. Anderson and Rappaport [28] conducted study for 60GHz which has higher range for outdoor environments but behave worst in complex indoors. Similar study conducted by [25] shows path loss because of trees and spaces outside home at 5.8GHz is higher than lower frequencies. Other studies carried by Devasirvatham et al [30], and Aguirre [31] also emphasizes the effect of higher frequencies on path loss. Recently a Doppler radar based device operating at 1.15GHz has been introduced in [19]. Zhao Li [21] performed experiments for IRUWB radar at 270 and 400MHZ respectively. This much lower frequency encounters obstacles but have low path loss and is very useful for rescue efforts. But these radar based solutions are costly and are not much ubiquitous.

Results have provided immense insight on the application of Wi-Fi Halow. The emergence of Wi-Fi Halow which is primarily for complex indoor environments will revolutionize the ubiquitous systems. It has been designed mainly for IoTs. Application of Wi-Fi Halow in collapsed structured environment may help in rescue in the future. This work of coverage distance estimation at other bands can also trigger researchers to propose new path loss models for these collapsed indoor environments. It will reduce the cost and will have ease in access as smartphone market is growing day by day.

VII. Conclusion

In this paper, we have investigated the possible application of Wi-Fi signals in collapsed structures. Wireless signals are badly affected in these environments mainly because of multiple obstacles. Our work dealt with the estimation of Wi-Fi signals distance coverage in aforementioned scenario. It is concluded that Wi-Fi Halow overtook other Wi-Fi bands hence triggering application of Wi-Fi signals for obstructed and complex structures. This work provides insight for higher signal penetration for Wi-Fi Halow primarily because of brick wall collapsed structure and less obstructions as well. In the future, we can consider complex debris caused by concrete, brick and metallic structures to further evaluate Wi-Fi Halow. This work also suggests that Wi-Fi based rescue from collapsed structure can replace traditional radar based techniques. This is first work of its kind which can pave way for cost effective and ubiquitous post-disaster rescue in the future.

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