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Wi-Fi Halow Signal Coverage Estimation in Collapsed Structures

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***Abstract*—With the growing research for IoTs particularly wireless signals as sensors, Wi-Fi has witnessed an increasing trend for numerous applications.In this study, we investigate the feasibility of Wi-Fi Halow signals for collapsed structured environments. The objectives of this paper are first to consider a complex debris scenario and then wireless signal coverage under this debris has to be computed. A modified path loss model known as PL-Collapsed along with complex collapsed structure layout has been used for proper reception of echo which provides the probable coverage for aforementioned scenario. Objectives have been realized with proper simulations. Then, we compare the results for various signal intensities, antenna gains and debris layers. Comparison of results show that Wi-Fi Halow at low power with higher antenna gains has better coverage. It is therefore paving way for post-disaster rescue through IoTs in comparison with traditional radar techniques.**

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

I. Introduction

With the advent of internet of things (IoTs), our lives are becoming more dependent on ubiquitous systems [1] [2]. Sensors and wearables are essential part of IoTs but now research has much focused on device free communication [3] [4]. This essentially include wireless devices at a low power to be acting as sensors particularly Wi-Fi signals that have additional roles than sole Internet connectivity medium. [5] [6]. These signals are very much effective for indoor environments where mostly IoTs are deployed [7].

Application of Wi-Fi for indoor environments has received much attention because of complexity and nature of civil structures where wireless signals pass through direct or multipath. It is also because of global positioning system which is not suitable for indoor scenarios [7] [8]. Wireless signals convey information that typifies the environment when these pass through indoor physical spaces [5]. This becomes more troublesome in case of collapsed structure where multiple objects constituent of various materials cause more signal distortion eventually completely fading the wireless signals [9] [10]. And penetration of wireless signals under collapsed structure is more important because it can lead to post disaster rescue as existing solution are expensive and are not available in developing countries where most of the collapses occur.

The main objective of this paper is to focus on feasibility of Wi-Fi Halow signals and its coverage for collapsed structures. Wi-Fi Halow is primarily for IoTs and has good penetration for complex indoor environments. This is because of its operation at lower frequency i.e., 900MHz. So, having this understanding, we envisage that these signals can be effective for collapsed structures where we can rescue lives. This can turn into complete ubiquitous post-disaster rescue solution with device free communication because of Wi-Fi Halow replacing the traditional IoTs where traditionally, there is need of cyber-physical systems or robots.

In this paper, we employ a compendious model PL- Collapsed for path losses in collapsed structures which ensures effective computation of coverage of weak Wi-Fi signals. In our approach, we also consider debris model which is constituent of brick, concrete, glass and lumber as materials. The objective of this study is to estimate the coverage of Wi-Fi signal through our debris model while employing PL-Collapsed. The placement of transmitter and receiver i.e., Wi-Fi is considered to be outside of debris to model it like a real environment. The transmitter continuously sends signals like Doppler radar which pass through debris and face attenuation because of complexity of layout, materials and causes multipath. This multipath fading, attenuations, reflections and scattering weakens the already weak Wi-Fi signals. These signals reflect back to receiver after facing so much attenuations from debris model and provide coverage information. We have modelled collapsed structure having specification of brick 10.5″, concrete 8″, glass (6mm), glass (13mm) and lumber (76mm). These specifications have been considered based on construction style of developing countries. We have also considered minimum detectable signal strength which guarantees the quality of echo as it contains all vital information for rescue [5].

The main contributions of this paper are:

- We envisage the PL-Collapsed for attenuation and path losses for brick and concrete collapsed structures.
- We make an investigation of Wi-Fi Halow signal behavior for collapsed structure through our debris model.
- Finally, we validate our model for low power Wi-Fi Halow. This work highly emphasizes on future IoTs which would be based on sensor less sensing.

We organize this paper as follows: Section II provides more depth on background and related work whereas Section III de-

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scribes our problem formulation. We discuss our modified path loss model for coverage in Section IV. Simulation results have been provided in Section V. Section VI completely analyzes the work and compare it prior works. Finally, Section VII concludes the paper.

II. Background and Related Work

In this section, we provide deep insight to significance of this work by articulating the background and related work. Firstly, factors pertaining to wireless signal under collapsed structure are presented. These include path loss modelling and attenuations under debris. Afterwards, applications of wireless signals using various technologies for rescue have been discussed. Finally, we provide the problem statement based on this background and related work.

Wireless signals face reflections, attenuations and scattering on being exposed to objects in their path of communication. This weakens the wireless signals and range is highly affected. Considering the collapsed structure environments, it becomes more cumbersome as there are layers of objects laying over each other hence forming a debris. So, these attenuations caused by scattering and losses make it difficult for wireless signal to penetrate through debris [9]. DiCarlofelice and E. Di-Giampaolo [10] [11] conducted localization of radio emitters into collapsed buildings after an earthquake. They conducted a measurement campaign in a typical European historical city, LAquila, which was stroke by a severe earthquake [5]. Identification of best radio band for signal penetration under debris is subject of great importance. A study was conducted by [9] for 50 MHz, 150MHz, 225MHz, 450MHz, 900MHz, and 1.8GHz. Similarly, there has been research conducted on structural health monitoring as in [12] [13] [14], which also provide intuition about wireless signal applications for complex environments.

The fundamental challenge to deal with attenuations and losses encountered to wireless signals under collapsed structure is effective path loss modeling. Unfortunately, there is very few significant work done for path loss computation in context of this scenario as [15]. Although, there is enough literature available for path loss modelling in other outdoor and indoor environments which provide us insight towards their application in collapsed cases. A systematic survey of path loss prediction methods, covering more than 60 years of incessant research has been presented in [7] [16]. Rappaport [8], firstly proposed path loss modelling for complex environments. Afterwards, many researchers put emphasis in this domain with studies like [17] [18]. There are also some studies related to Wi-Fi bands such as [5] [19] and [20].

Finally, we discuss existing techniques that employ wireless signals for possible rescue under collapsed environment. Although, there are several tools and technologies available for detection of human activity under debris such as sound sensor [21], micro-cameras [22],wireless sensors [23] and radars [24] but the most favored method is radar based sensing. It is because of the fact that it has better ability to penetrate deep through dielectric barriers. The most types of radar used in rescue efforts are Doppler radars [24] [25] [26], Ultra-wideband(UWB) radars [27], IR-UWB radars [28] and Continuous Wave Stepped Frequency (CW-SF) Ground penetrating radar [29]. These approaches work on different frequencies ranging from lower to higher such as 270MHz, 400MHz [28] to 1.15GHz [26]. These technologies are also expensive and their availability in developing countries is still a question. These technologies are also not feasible for complex structures hence limiting their applications.

In a nutshell, we observe that most of the current rescue solutions using wireless signals are mainly based on radars and cannot be considered as ubiquitous. These solutions are quite expensive and also not available in third world countries where most of the collapses occur. As to date, there is no ubiquitous solution particularly Wi-Fi Halow based one for coverage estimation in collapsed structure which can maximize rescue efforts. In the light of related work, we are certain that investigation of Wi-Fi Halow for collapsed structures if proved to be successful can make a turnaround in ubiquitous solutions.

III. Problem Formulation

In this section, we present problem formulation. We firstly investigate the wireless signal behavior in collapsed structures with an echo model followed by debris model which simplifies our problem.

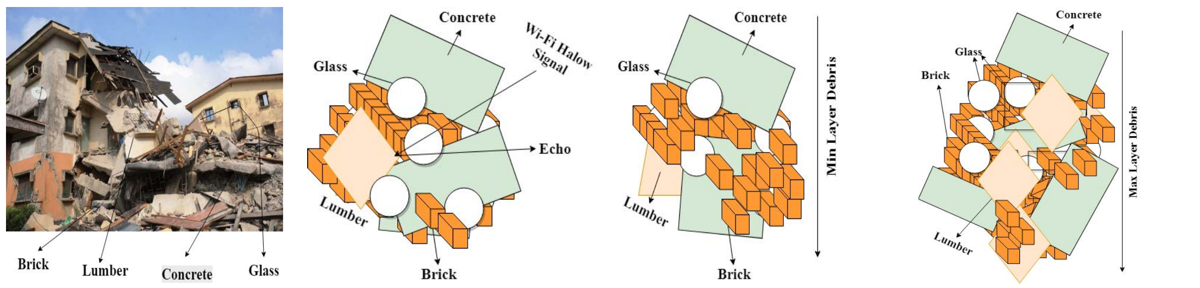
A. Wi-Fi Halow Signal and Echo Model

Indoor environments have relatively complex structures as these are constituent of multiple objects, walls, halls etc., so wireless signal faces many attenuations and becomes weak. When it comes to collapsed structure, the case becomes more worse as even single wall may turn up to multiple objects. It is evident that by considering whole collapse structure where debris has hundreds of pieces, wireless signal penetration becomes a nightmare. And it becomes even worse for weak Wi-Fi signal to penetrate into it.

In order to simplify the problem, let us consider a small indoor collapsed structure consisting of brick, concrete, glass and lumber only as shown in Fig 1a. This shows that aforementioned structure has turned into multi object scenario where each object having different thickness level which defines the Wi-Fi signal penetration.

In order to address the coverage issue, we employ echo model which works like Doppler radar. Wi-Fi transmitter radiates its signals simultaneously that can take many paths but for simplicity of problem, we have only considered directional lobe of antenna. When this signal passes through collapsed structure as model shown in Fig 1b, it will face multiple attenuations and fading. These fading will be of every type like multipath fading to shadowing, fast fading to slow fading which in turns weaken the signal. This weak signal will return back after facing so much reflections.We properly consider MDS for wireless signals to ensure quality reception of echo [5].

Normal Wi-Fi signals operate at higher frequencies i-e,. 2.4GHz and 5GHz and are more prone to attenuations. On



(a) Simple Collapsed Structure (b) Signal and Echo Model (c) Minimum Layer Case (d) Maximum Collapse Case

Fig. 1: Illustration of collapsed structure with echo and layered models

the other hand, Wi-Fi Halow is latest technology operating at sub 1GHz and is specifically designed for obstructions and attenuations. So, in our signal model, we consider Wi-Fi Halow for collapsed structures as it has good penetration for obstructions and can pave way for ubiquitous solution in post-disaster rescue as there is enough research done to estimate the breathing behavior on normal Wi-Fi band in normal indoor environments [30] [31].

B. Debris Model

Selection of proper debris is pivotal to estimate the coverage. Collapsed structures may have multi-material debris but here we only consider brick, concrete, glass and lumber based debris. We assume that after collapse, structure turn up into pieces laying over each other. We also assume that collapse is caused by an earthquake. We define layers based on this fact of pieces laying over each other and make a debris model like in Fig 1c. Debris has vertical and horizontal layers but more important are vertical layers as these define the depth of debris. The signal penetration of horizontal and vertical layers will be almost same but in order to address the most important depth issue, we only consider vertical layers. All debris materials as considered above have their own attenuation behavior for various frequencies. We have considered both normal depth and deep depth cases with Fig 1d showing the common depth scenario whereas Fig 1c depicting complex debris layers. It is evident that each adding piece will cause more obstructions, so deeper the debris, higher the attentuation which results in lower penetration.

So, in brief, our problem is to address coverage (which can further assist in rescue) in collapsed structure based on MDS threshold [5]. This coverage various with respect to transmitter intensities, antenna gains, minimum detectable signal threshold and debris model. We estimate the coverage with these aforementioned aspects and predict the Wi-Fi Halow signal behavior for collapsed structures.

IV. Approach: PL-Collapsed

In this section, we present PL-Collapsed. This model considers echo and debris model along with geometry of transceivers to compute coverage. Path losses incurred to Wi-Fi signal in collapse structures define the validity of model.

The placement of Wi-Fi Halow accentuates the signal penetration in collapsed structures. We assume that directional lobe of antenna is only the main lobe in order to avoid multiple aliased signal reflected from undesired sources. We also assume that there is no other transmitter and no other sources of noises. Wi-Fi signal penetration in collapsed environments can be realized by considering link budget equation given as;

$$P_{rx} = P_{tx} + G_{tx} + G_{rx} - PL \tag{1}$$

where G and P is antenna gains and power for transceivers. The term PL defines path losses incurred to signal because of debris. It becomes more apparent when signal tries to deeply penetrate into debris with the increasing distance.

Wireless signal propagation for our debris model will consist of two parts. Firstly, it will travel in free-space and then it will penetrate through obstructed paths. This can be given as below;

$$PL = PL_{free-space} + PL_{debris} \tag{2}$$

Firstly, we analyze the path loss in free space. We assume that Wi-Fi signal will travel only 1 meter before entering to debris. We also make assumption that there is no other obstacle between Wi-Fi signal transmitter to debris. This signal will penetrate through our debris model after traveling through free-space where it will face much attenuations primarily because of debris layers formed after collapse laying horizontally or vertically. Path loss in debris can be derived using distance dependent path formula. It states that path loss increases exponentially with the distance given in log form as below;

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

where PL_{debris} is path loss in debris and $PL(d_0)$ is free space path loss for d_0. There is no $PL(d_0)$ in debris, so, free-space path loss is only computed for outside space of debris. α is path loss exponent which also varies with environments ranging from 2 for free-spaces to 6 in case of obstacles consisting metallic objects as well. We assume it to be 5 as there is no high attenuation metallic source under consideration. Now, in order to incorporate attenuations of multiple layers of debris, (2) can be rewritten as;

$$PL = PL_{free-space} + 10 * \alpha * \log_{10}(\frac{d}{d_0}) + X_g \quad (4)$$

X_g is new term introduced here which includes all possible losses. Wi-Fi signal faces much attenuation because of reflections, scattering, multiple paths, diffractions and fading. The most evident form of fading in our case are both slow-fading and fast-fading but for simplicity of approach, we have only exploited attenuation factor without going into modification of those models. (2) with addition of possible attenuation will be as follows;

$$\begin{aligned} PL = {} & PL_{free-space} + 10 * \alpha * \log_{10}(\frac{d}{d_0}) \\ & + l * AF(Bricklayer) + m * AF(ConcreteLayer) \\ & + n * AF(Glass(6mm)Layer) \\ & + o * AF(Glass(13mm)Layer) \\ & + p * AF(Lumber(76mm)Layer) \end{aligned} \quad (5)$$

where l, m, n, o, and p denotes number of layers for our considered materials. AF is attenuation factor caused by single layer of brick, concrete, glass and lumber respectively. Thickness of materials will also define the complexity of layers and attenuation values vary accordingly.

Finally, we consider the echo signal which has desired information for rescue. It means the strength of received signal which conveys proper information about breathing signals under debris. Wi-Fi signals have feature known as channel state information(CSI) which contains the sensing information. This CSI can further help in post-disaster rescue. In order to achieve required echo, the received power should be above or equal to pre-defined threshold termed as 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;

$$P_{tx} + G_{tx} + G_{rx} - PL \geq MDS(P_e) \quad (6)$$

V. Simulations

This section discusses the simulation method and provide results. Simulation parameters vary with the environments primarily because of regulatory bodies like Federal Communications Commission (FCC)[1].

A. Simulation Method

Right selection of simulation parameters is essential to have better results. We have performed simulations on MATLAB 17a on 64bit OS with 16GB RAM and Intel(R) Xeon(R) 3.3 GHz CPU as per simulations parameters shown in Table I.

The operating frequency for Wi-Fi Halow is provided in Table I, which is regulated by IEEE Task Group [32]. We have considered the frequency case for US(902MHz), Japan(915MHz) and Korea(917MHz). These countries have their own spectrum limits and power considerations for Wi-Fi Halow as in [32]. Similarly variance in transmission power and antenna gains is regulated with FCC para 17.245 rules for PTMP (Point to multi-point). Antenna gain varies from 6dBi to 26dBi in relation with transmitted power. Wi-Fi Halow follows same behavior for power increase in relation with decrease in antenna gain to that of 2.4GHz and 5GHz spectrum as given in regulations[2].

TABLE I: Simulation Parameters

Parameter	Values
Operation Frequency	(902, 915,917)MHz
Transmission Power	(30, 24, 23, 13, 10) dBm
Antenna Gains	(6, 12, 13, 23, 26) dBi
Debris Type	Brick, Concrete, Glass, Lumber
Attenuation of Brick 10.5″	7dB at 900 MHz
Attenuation of Concrete 8″	23dB at 900 MHz
Attenuation of Glass (6mm)	0.8dB at 900 MHz
Attenuation of Glass (13mm)	2dB at 900 MHz
Attenuation of Lumber (76mm)	2.8dB at 900 MHz
Minimum Debris Layers	15 (4b+2c+6g+3G+2l)
Maximum Debris Layers	34 (10b+4c+10g+6G+4l)
Modulation Type	256QAM, 16QAM
Channel BW at 256QAM	1MHz
Channel BW at 16QAM	16MHz, 1MHz
MDS Threshold at 256QAM	-70dBm
MDS Threshold at 16QAM	-71dBm, -83dBm
Path Loss Exponent	5

As mentioned earlier that collapsed structure may constitute various materials. We have considered four types of debris constituent's based on real construction scenarios in developing countries. These are brick″, concrete8″, glass(6mm), glass(13mm) and lumber(76mm). The depth of these materials define the complexity of collapsed structures. The attenuations caused by single layers of under consideration materials have been provided by Digi [3]. We also select debris layers which defines the nature of collapsed structure. Most of the buildings in developing countries are not sky scrappers; so, we have assumed debris layers between 15 to 34 for simulations in order to have insight about Wi-Fi Halow Signal in collapsed environments. The minimum detectable signal threshold which is much important for better echo reception; specifically for our case as Quadrature amplitude modulation(QAM); is assumed to be -70dBm for 256QAM case with 1MHz channel bandwidth. Similarly, for lower modulation scheme i.e., 16QAM, -71dBm and -83dBm values have been considered for MDS threshold with 16MHz and 1MHz channel bandwidth respectively. Higher QAM ensures better data rate but noise and interference are also evident. That is why, we have considered both low and high QAM case to have better understanding of Wi-Fi Halow. Finally, we select path loss exponent as 5 in order to cope with cluttered environment.

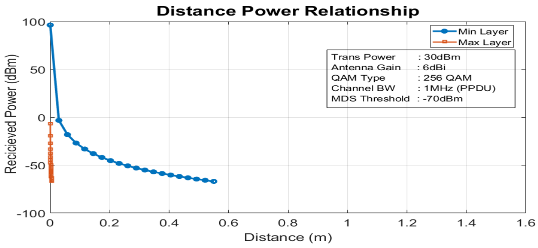
[1]https://www.fcc.gov/tags/radio-rules

[2]https://www.air802.com/fcc-rules-and-regulations.html

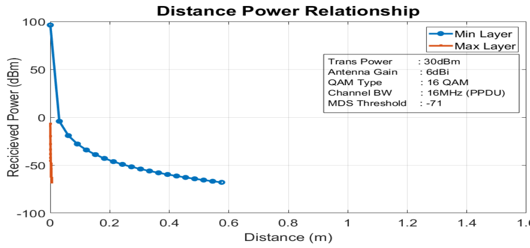
[3]http://ftp1.digi.com/support/images/XST-AN005a-IndoorPathLoss.pdf

TABLE II: Coverage Range with Various Materials

Transmit Power (dBm)	Max Antenna (dBi)	Brick Attenuation 10.5″ (dB)	Concrete Attenuation 8″ (dB)	Glass Attenuation 6mm (dB)	Glass Attenuation 13mm (dB)	Lumber Attenuation 76mm (dB)	Range in Collapsed Structure (m)			
							256QAM (1MHz)		16QAM (16MHz)	
							Min L	Max L	Min L	Max L
							4b+2c+6g +3G+2l	10b+4c+10g +6G+4l	4b+2c+6g +3G+2l	10b+4c+10g +6G+4l
30	6						0.5502	0.0048	0.5761	0.0051
24	12						1.2605	0.0111	1.3199	0.0116
23	13						1.4472	0.0127	1.1514	0.0133
		7	23	0.8	2	2.8	256QAM (1MHz)		16QAM (1MHz)	
13	23						5.7234	0.0503	10.4149	0.0915
10	26						8.6552	0.0761	15.7498	0.1384

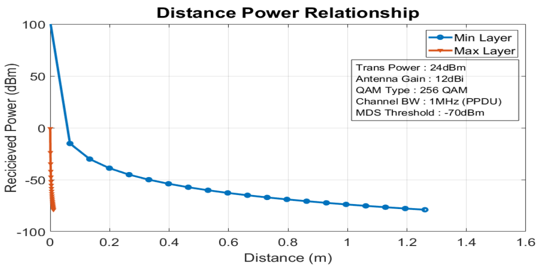


(a) 256QAM, 1MHz Channel

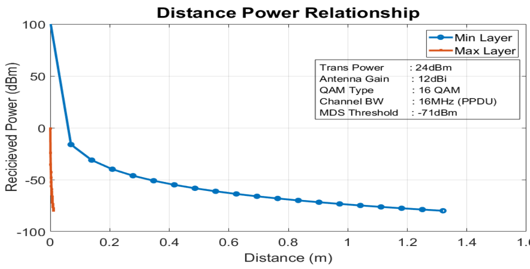


(b) 16QAM, 16MHz Channel

Fig. 2: 30dBm, 6dBi Scenario



(a) 256QAM, 1MHz Channel



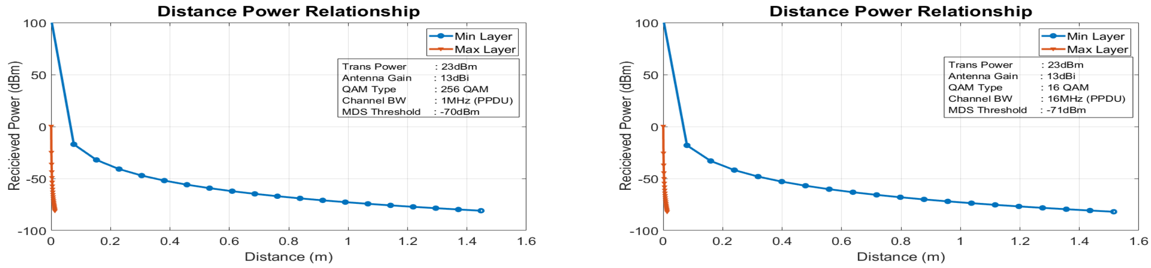
(b) 16QAM, 16MHz Channel

Fig. 3: 24dBm, 12dBi Scenario

B. Simulation Results

We performed simulation on afore-discussed parameters. Results as displayed in Table II have shown an increasing trend of coverage with lowering the transmitter intensity. Table II also depict Wi-Fi Halow signal frequency behavior for different debris layers across varied signal intensities and antenna gains. Overall, we performed 20 simulations with varied parameters. Finally, we compare the results for best power level which should be low enough to fit it for IoT based solutions.

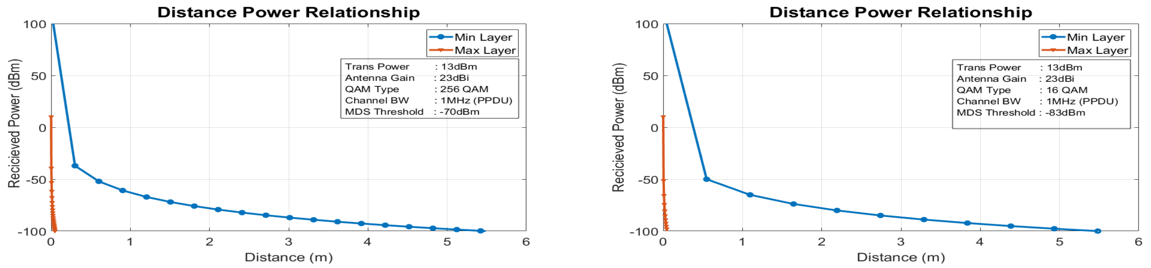
1) Comparison w.r.t Signal Intensity: Let us compare simulation results for various Wi-Fi Halow signal intensities across different debris layers with varied modulation types and channel consideration. The distance power relationship for these intensities has been shown in Fig 2 to Fig 6. It can be observed that higher transmission power provides low coverage, e.g 30dBm power with 256QAM covers 0.5502m and 0.0048m respectively for min and max layer scenario in debris. On the contrary, 10dBm power with 256QAM covers 8.6552m and 0.0761m respectively for same debris type. This make us believe that Wi-Fi Halow operating at lower power provide better coverage. This comparison has been illustrated in Fig 7, where an increasing signal coverage can be seen with lower power, higher antenna gain and lower QAM type.



(a) 256QAM, 1MHz Channel

(b) 16QAM, 16MHz Channel

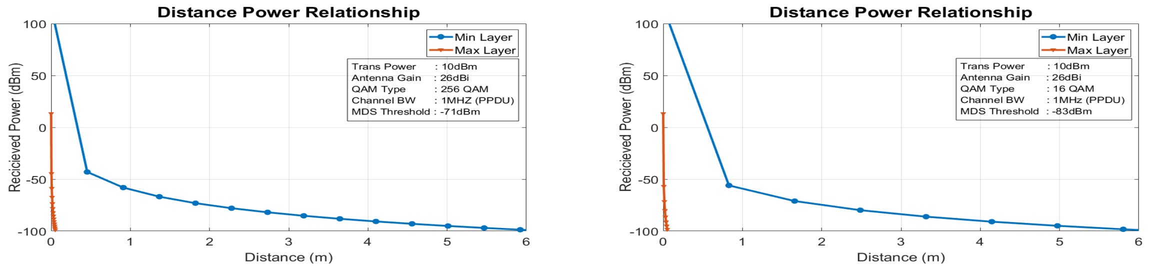
Fig. 4: 23dBm, 13dBi Scenario



(a) 256QAM, 1MHz Channel

(b) 16QAM, 16MHz Channel

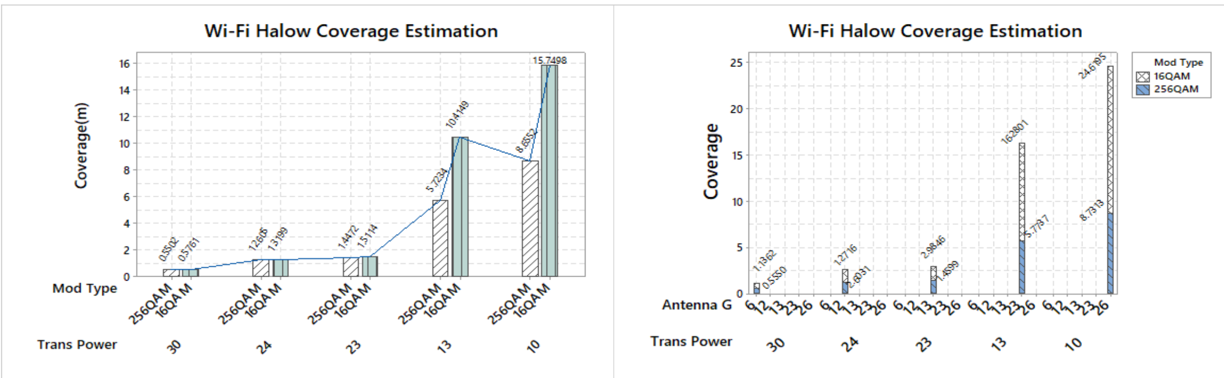
Fig. 5: 13dBm, 23dBi Scenario



(a) 256QAM, 1MHz Channel

(b) 16QAM, 16MHz Channel

Fig. 6: 10dBm, 26dBi Scenario



(a) Comparison w.r.t modulation scheme

(b) Stacked graph comparison

Fig. 7: Comparison of Trans Power, Antenna Gain and Coverage

2) Comparison w.r.t Signal Modulation Type: In this subsection, we compare Wi-Fi Halow signal coverage on the basis of channel bandwidth and modulation coding scheme being considered. Both cases of debris layers are tested for 256QAM with 1MHZ and 16QAM with (16MHz, 1MHz) channel bandwidths respectively. Wi-Fi Halow frequencies for US, Korea and Japan operate in 1MHz for QAM256 but differ with 16QAM, where these still operate in 1MHz channel bandwidth. Let us consider 24dBm power as an example for comparison of coverage for modulation coding schemes. Simulation results for this case are shown in Fig 3a and 3b respectively. It can be observed from these results that 16QAM perform better than higher QAM value i.e.,256QAM. We illustrate overall comparison of coverage on base of modulation type in Fig 7.

3) Comparison w.r.t Debris Type: Finally, we compare the Wi-Fi Halow signal behavior for our proposed debris cases. We observe that minimum layer scenario perform better than maximum layer. This can be seen in all simulation results across various signal intensities and modulation schemes from Fig 2 to Fig 6. In order to show better performance, we compare 10dBm power case as shown in Fig 6. The coverage for QAM256 under min layer scenario is 8.6552m, whereas for max layer; it is 0.0761m. It is quite evident from both values that signal performs better in lower layered debris. Similarly, for same power level but with QAM16, the coverage distance for min layer has risen to 15.7498m in contrast with max layer case, where it is 0.1384m. So, it can be concluded that increasing the debris layers will cause more attenuations for which we need to increase signal strength through various means in order to have deep coverage.

VI. Performance Analysis

In this section, a deep analysis of our work is provided with proper background, contributions and insight for future. Firstly, there is need to identify the complexity of problem. Afterwards, contributions and comparison with existing works in relevant domain is to be compared for justification of this work. Finally, a discussion is made on importance and application of Wi-Fi Halow for possible rescue as a future work.

In this work, we estimated Wi-Fi Halow signal coverage in collapsed structures. These environments are very complex in nature as buildings after collapse form multiple layers of debris depending on the type of collapse, causes and buildings structural constituent. This debris makes multi-layered case where wireless signals behave extremely poor. This is one of the main reason that still manual rescue is going on around the world in case of collapses. There is very little work done on the application of wireless signals for collapsed environments. Most of these studies like [11] [24] [29], make use of radar based approach but could not provide desired results except providing insight about application of wireless signals in collapsed structures. These techniques are also costly and can not be deployed in developing countries where most of the collapses occur because of low engineering standards and poor management. Considering the ubiquitous solutions converging in daily life, we are certain that there is also need to investigate IoT based solutions for rescue. Wi-Fi signals are available in almost every country and recently presented Wi-Fi Halow operating at lower frequency can realize our goal.

We mostly prefer power efficient IoT devices. In this work, we have simulated Wi-Fi Halow across different power level and figured out that low transmission power provides us better results. Secondly, it is operating at sub 1GHz frequency in comparison with traditional Wi-Fi signals which operate at 5GHz and 2.4GHz respectively. We have considered modified path loss model similar to [7] [8] which take complex structure into consideration. If we compare this work with existing path loss models, it can be concluded that most of the works like [9] [17] [20] [33] [34] provide path loss computation for various environments but none of these deal with collapsed structures.

Finally, we discuss the possible application of low power of Wi-Fi Halow for collapsed environments. In order to have efficient rescue, we need to fulfil two conditions. These are breathing or heart beat detection and localization of alive one under debris. Interestingly, there are researches on the application of Wi-Fi signals for breathing detection [35] and localization [36] [37] [38] at 2.4GHz. So, in order to have ubiquitous solution, there is need to map both applications under debris scenario where 2.4GHz performs poorly but Wi-Fi Halow provide better results. So, we can rightly say that research on breathing and localization using Wi-Fi Halow signals in collapsed environments may revolutionize the rescue operations in the future.

VII. Conclusion

In this paper, the application of Wi-Fi Halow for collapsed structure was under consideration. Wireless signals are severely affected in collapsed environments. It is because of complex debris which causes higher attenuation. This work dealt with the behavior of Wi-Fi Halow signal at different intensities, geometry of transceivers and complexity of debris in order to have better coverage which may return echo with desired information. Future research can be carried on increasing the coverage distance under collapsed environment which can then further trigger post-disaster rescue with IoTs.

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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] A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, "Internet of things: A survey on enabling technologies, protocols, and applications," *IEEE Communications Surveys & Tutorials*, vol. 17, no. 4, pp. 2347–2376, 2015.

[3] M. Zhao, F. Adib, and D. Katabi, "Emotion recognition using wireless signals," in *Proceedings of the 22Nd Annual International Conference on Mobile Computing and Networking*, ser. MobiCom '16. New York, NY, USA: ACM, 2016, pp. 95–108. [Online]. Available: http://doi.acm.org/10.1145/2973750.2973762

[4] 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.

[5] M. F. Khan, G. Wang, M. Z. A. Bhuiyan, and X. Li, "Wi-fi signal coverage distance estimation in collapsed structures," in *2017 IEEE International Symposium on Parallel and Distributed Processing with Applications and 2017 IEEE International Conference on Ubiquitous Computing and Communications (ISPA/IUCC)*. IEEE, dec 2017.

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

[7] 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.

[8] 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.

[9] 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.

[10] A. D. Carlofelice, E. D. Giampaolo, M. Elaiopoulos, M. Feliziani, M. Roselli, and P. Tognolatti, "Localization of radio emitters into collapsed buildings after earthquake: Measurements of path loss and direction of arrival," in *International Symposium on Electromagnetic Compatibility - EMC EUROPE*, Sept 2012, pp. 1–6.

[11] 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.

[12] 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.

[13] 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.

[14] 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.

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

[16] M. F. Iskander and Z. Yun, "Propagation prediction models for wireless communication systems," *IEEE Transactions on Microwave Theory and Techniques*, vol. 50, no. 3, pp. 662–673, Mar 2002.

[17] H. Okamoto, K. Kitao, and S. Ichitsubo, "Outdoor-to-indoor propagation loss prediction in 800-mhz to 8-ghz band for an urban area," *IEEE Transactions on Vehicular Technology*, vol. 58, no. 3, pp. 1059–1067, March 2009.

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

[19] 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, thirdquarter 2015.

[20] L. Liechty, E. Reifsnider, and G. Durgin, "Developing the best 2.4 ghz propagation model from active network measurements," in *2007 IEEE 66th Vehicular Technology Conference*, Sept 2007, pp. 894–896.

[21] H. Sun, P. Yang, L. Zu, and Q. Xu, "A far field sound source localization system for rescue robot," in *2011 International Conference on Control, Automation and Systems Engineering (CASE)*. IEEE, jul 2011.

[22] N. Doulamis, P. Agrafiotis, G. Athanasiou, and A. Amditis, "Human object detection using very low resolution thermal cameras for urban search and rescue," in *Proceedings of the 10th International Conference on PErvasive Technologies Related to Assistive Environments*, ser. PETRA '17. New York, NY, USA: ACM, 2017, pp. 311–318. [Online]. Available: http://doi.acm.org/10.1145/3056540.3076201

[23] 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 *2011 3rd International Conference on Awareness Science and Technology (iCAST)*, Sept 2011, pp. 221–226.

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

[25] R. M. Narayanan, "Earthquake survivor detection using life signals from radar micro-doppler," in *Proceedings of the 1st International Conference on Wireless Technologies for Humanitarian Relief*, ser. ACWR '11. New York, NY, USA: ACM, 2011, pp. 259–264. [Online]. Available: http://doi.acm.org/10.1145/2185216.2185288

[26] F. JalaliBidgoli, S. Moghadami, and S. Ardalan, "A compact portable microwave life-detection device for finding survivors," *IEEE Embedded Systems Letters*, vol. 8, no. 1, pp. 10–13, March 2016.

[27] 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.

[28] 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 *2014 IEEE Topical Conference on Biomedical Wireless Technologies, Networks, and Sensing Systems (BioWireleSS)*, Jan 2014, pp. 31–33.

[29] 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.

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

[31] J. Liu, Y. Wang, Y. Chen, J. Yang, X. Chen, and J. Cheng, "Tracking vital signs during sleep leveraging off-the-shelf wifi," in *Proceedings of the 16th ACM International Symposium on Mobile Ad Hoc Networking and Computing*, ser. MobiHoc '15. New York, NY, USA: ACM, 2015, pp. 267–276. [Online]. Available: http://doi.acm.org/10.1145/2746285.2746303

[32] "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.

[33] C. R. Anderson and T. S. Rappaport, "In-building wideband partition loss measurements at 2.5 and 60 ghz," *IEEE Transactions on Wireless Communications*, vol. 3, no. 3, pp. 922–928, May 2004.

[34] A. Durantini and D. Cassioli, "A multi-wall path loss model for indoor uwb propagation," in *2005 IEEE 61st Vehicular Technology Conference*, vol. 1, May 2005, pp. 30–34 Vol. 1.

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

[36] X. Wang, L. Gao, S. Mao, and S. Pandey, "CSI-based fingerprinting for indoor localization: A deep learning approach," *IEEE Transactions on Vehicular Technology*, pp. 1–1, 2016.

[37] 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.

[38] 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.