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Design Considerations of MoHotS and Wireless Chain Networks

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Abstract. This paper introduces and discusses MoHotS and wireless chain networks. The paper proposes integration of unused capacity in hot spots. We discuss the area of coverage and the probability of making connections in wider area wireless networks based on MoHotS. The area of coverage of MoHotS is evaluated for MoHotS on highways. It also addresses the limits of interference in networks of wireless MoHotS and chain networks. It is shown that the interference from other MoHotS converges for large *N* and is tamed by the path loss exponent. Terrain characteristics are described as well.

Keywords: mobile hot spots, chain networks, mobile networks, area of coverage, interference, path loss exponent

1. Introduction

The term “hot spot” is used with two meanings in wireless communications. Traditionally, it is used to refer to an island of wireless local area network (WLAN) that is deployed in an isolated manner at a location. The term has also been used by a few authors to refer to areas of traffic congestion in cellular communication. The first meaning is intended in this paper. VSATS, LEO (MEO) satellites, UAV, HAPS, balloons and wireless networks carried on mobile platforms such as cars, trains, ship and aircrafts all belong to a common area of communication which is termed in this paper as MoHotS or mobile hot spots. The term MoHotS therefore refers to both single node on a moving vehicle and many nodes deployed on a moving vehicle. In the case of multiple nodes, they form a MoHotS subnet.

The last four years have witnessed rapid deployment of WLAN hot spots. The next decade will be the decade of MoHotS and integration of fixed hot spots so that unused capacity held by individual owners of WLAN hot spots can be pooled into a common ‘grid’ to provide broadband access as of now distributed in homes and private institutions. Not much has happened in this regard because the attention of researchers and the public is focused on cellular communications as we know it today. Cellular communication is however changing and the changes could be massive once devices that are truly multi-standard, with ad hoc network capabilities, are ubiquitous in the public domain. In what follows we provide preliminary treatment of mobile hot spots, techniques for larger range reach and interference limitations.

Unused access capacity in 802.11a/b/g hot spots lies fallow in most places. The application of MoHotS can result to a wide area network by pooling of the unused capacity. Furthermore, they can be made to relay data for and from each other. When this happens, reliance on cellular and fixed network operators for data relays within local settings will decrease and better usage of spare capacity will result. These islands of wireless LANs (WLAN) interfere with each other and in a densely populated area with high penetration of WLANs, it is essential to consider how best to use all the excess capacity provided by each ’personal operator’ and also how to mitigate the rise in interference. To the author’s knowledge this is the first paper that discusses in a structured manner the issues involved in developing wide area networks using multiple mobile hot spots.

The rest of the paper is organised as follows. In Section 2 MoHotS are introduced by discussing mobile wide area network (MWAN) of mobile hot spots. Different types of MoHotS are introduced and explained in this section including coverage holes. Section 3 presents a topological application of MoHotS in terms of chain networks. Relaying of information and the probability of making a connection are discussed in detail. Section 4 covers interference limits in MoHotS. The general aspects of the market effects of multiple neighbouring interferers and their limitation are discussed using chain networks as an example. This section is concluded with a detailed analysis of the types of terrains in which MoHotS will operate in practice including considerations for highways, tunnels and urban areas. Path loss exponents for such environments are given as guides for further design. In Section 5 conclusions are drawn.

2. Wide Area Networks of Mobile Hot Spots

A spot network provides spot communication coverage over a limited area. A fixed spot network provides fixed area of coverage and both the size of the coverage and also the position of the coverage are fixed. Cellular networks may be considered as linked fixed spot networks, provided by the fixed base stations. A geosynchronous satellite is another example of a spot network providing permanent footprint at specific places on the earth’s surface. Example of spot networks also include fixed or tethered balloon carrying communication infrastructure in space.

A mobile spot network is carried by a moving platform and the area of coverage could be fixed or dynamic and the location of the spot is dynamic. As the vehicle carrying it speeds away the spot coverage emerges and disappears at the speed of the vehicle carrying the node or router. The appearance and disappearance of spot coverage is not periodic in this case. Periodic transmission method is akin to what obtains in LEO satellite communications in which periodic coverage is provided based on the rotations of the satellites and earth The difference in the case of spot network is that the spot coverage may be available only temporarily because the vehicle carrying the node has just passed through the area and it may never return there again.

Spot coverage has a unique application in remote rural areas where for example a mobile router with a GPS connection visits isolated areas as it roams providing spot coverage for very shot periods of time to enable the residents of the areas to have access to a global wide area network for a period of time only. Spot networks can therefore be used to service many neighbouring remote hamlets with communication access on a daily or periodic basis. The spot node may also therefore serve while at a particular location as a relaying node to establish communication with a larger remote network.

To achieve large range coverage a spot network should have a backhaul either through a GPS, wide area cellular network, an HF radio or a fixed network infrastructure. Since a spot network is likely to be deployed in many different types of areas, effects of interference vary from place to place, are high in densely populated areas and low in rural and suburban areas.

MoHotS or mobile hot spot network access system is normally carried by a mobile platform such as a fleet of taxis, trucks, train and ships that allow either spot or continuous network

Table 1. Examples of flying network platforms [3, 4]

System	Energy use	Uptime	Coverage	Height	Payload	Data rate
Skyline (UK)	Via cable		5,000 km ^{2}	1.5 km		Fibre Optic, 1–2Mbps × 30,000 subscribers
ARC System (US)	Electricity via 2.5 cm cable		40,000 km^2	3–10 km	700 kg	Fibre optic cable, 1,500,000 subscribers per balloon
Sanswire Stratellite (US)	Solar cells	18 Months	337,000 km^2	20 km	$>$ 900 kg	33Mb banwidth
StratSat (UK)	Solar cells	5 yrs	18,000 km^2	20 km	1000 kg	>Mbps, 1000 billion calls a yr
Stratospheric Platform System (Japan)	Solar cells /fuel cells	3yrs	16 HAPS to cover Japan	20 km	1000 kg	20Mbps
Sky Station (US)	Solar cells	5–10 yrs	52,000 km^2	21 km	1000 kg	400,000 simultaneous 64 kbps and 1 ,000 multi-megabit transmissions

access between the mobile vehicles or tracking of goods as the vehicles move. The link between any two ***mohots*** is called a ***molink*** and the hop is called a ***mohop*** (mobile hop). A *molink* is dynamic and changes with the new positions of the mohots. Therefore, for each molink, the path loss exponent could be different to reflect the changed terrain between the mohots. Henceforth we will refer to these networks as MohotS.

The following infrastructure can be used to deliver MohotS. We divide them into two categories – on ground (water) or in the air. Ground based infrastructures include mobile vehicles (cars, trucks, trains) and on ships in water. This paper is about this set of platforms.

Network infrastructures on flying objects use low earth orbiting satellites (LEO), UAV and high altitude platform systems (HAPS). LEO satellites [2] are normally deployed in groups where either a single or multiple satellites expose regions on the ground with coverage access. The ground coverage area (footprint) of flying transmitters is proportional to the distance from ground to the object carrying the flying transmitter (LEO and HAPS). For HAPS, the foot print is given by the expression [3, 4]:

$$d = 2R\left(\cos^{-1}\left(\frac{R}{R+h}\cdot\cos(\theta)\right) - \theta\right) \tag{1}$$

R is the earth radius (6,378 km), h is the altitude and θ is the elevation angle. The minimum elevation angle is zero degrees. Several HAPS-based technologies are overviewed in [3] and they are summarised in Table 1.

Untethered flying objects such as high altitude platforms (HAPS) can also be used. HAPS have been widely studied [3–4]. HAPS will typically carry a communication infrastructure that allows spot coverage as it moves. HAPS are invaluable in uncovered difficult terrain (such as mountains, valleys, tunnels) and regions where deploying infrastructure could be prohibitively expensive. Rural China, India, Philippines and Indonesia with numerous islands to cover are typical areas where high altitude platforms can provide spot coverage cheaply. HAPS come in different flavours including UAV (Unmanned Aerial Vehicles) and untethered balloons. Since this paper is not about any of these specific technologies, the rest of the manuscript is focused on MoHotS and chain networks.

The life time of a hot spot is proportional to the diameter ($2r$) of the spot and inversely proportional to the speed of the MoHotS. The rate of spot coverage is given by the expression:

$$\tau_1 = \frac{A}{t} = \frac{Av}{d} \tag{2}$$

It is assumed therefore that the MoHotS traverses a distance equal to the life time of the spot it defines.

2.1. COVERAGE HOLES

MoHotS and chain networks are prone to developing areas not covered with radio frequency (RF) access, either temporarily or permanently. Such areas are referred to in this paper as holes. A coverage hole therefore can occur because the moving vehicle that provides coverage to that area leaves its location permanently and its function of supporting coverage and relaying of data is lost. This leaves a coverage hole.

Let each MoHotS be provisioned with a router and antenna with range R and coverage region Θ of angular extent less than or equal to 360 degrees. Assume that an omnidirectional antenna can be used to cover this region and also that sectoring is possible. When sectored antennas or directive antennas are used, coverage holes result and we will quantify this shortly. Let the width of a sector in degrees be θ with total angular coverage of extent: $\Phi_c \leq \Theta$. If there are S sectors, then the total angular coverage is given by the expression:

$$\Phi_c = \sum_{k=1}^{S} \Phi_k \tag{3}$$

The total coverage hole can therefore be estimated to be $\Phi_h = \Theta - \Phi_c$. Since the antennas expose different regions, the total coverage region is discontinuous and split. The extent to which the expected coverage region is split is:

$$\chi = \eta\Theta\sqrt{G} \tag{4}$$

G is the gain of the antenna and η is a constant. This expression is used in subsequent analysis to estimate the extent of uncovered areas in chain networks.

3. Chain Networks

Mobile chain networks are related to MoHotS. A mobile chain network is a field of Mohots linked together forming a functioning wide area network. A chain network is a network of MoHotS in which each footprint is either provided by a MoHotS or by multiple MoHotS. Therefore to provide wider coverage, we aggregate the coverage of the MoHotS in the network.

The mobile coverage area provided by M MoHotS is:

$$\Phi_c = \sum_{k=1}^{M} \Phi_{ck} \tag{5}$$

The extent of the uncovered areas (holes) is Φ_h. Given a highway situation with high density λ of vehicles carrying MoHotS, the probability of finding k MoHotS within a region R of area A is Poisson and is estimated with the expression:

$$P(k) = \frac{(\lambda.A)^k}{k!} e^{-\lambda.A} \tag{6}$$

We assume that the density of MoHotS is highly dynamic and during peak times the density of vehicles carrying MoHotS will be high and has Poisson distribution. This expression describes also the probability of having a given coverage.

We assume that the nodes or access points used by MoHotS can interwork. Despite this, several problems can block transmissions from MoHotS from reaching their destinations. Firstly, if there are no appropriate free MoHotS to relay data, or they are distributed at distances more than their individual communications range, the receiver will be isolated and cannot be reached. Therefore, it is necessary for relaying MoHotS to be located appropriately to establish an unbroken chain of connections or path. Secondly, if the called MoHotS is busy on a different call, it will be unavailable to establish connection to receive data. This can happen if the receiver runs out of channels or it has just a single channel to use for all time. Thirdly, if a called MoHotS is being used as a relay node, it is unavailable to attend to an incoming data. Fourthly, if no channels are available to the receiver to deploy to service the new call, the in-coming call will not reach its destination. Fifthly, because MoHotS are battery powered, the probability of MoHotS being drained of enough power to diminish its communications range is high.

3.1. RELAYING OF DATA IN CHAIN NETWORKS

A wireless chain network can use relay technology to achieve larger range reach in which data is relayed across chains of nodes (MoHotS) until it reaches the destination. In a chain network [1] neighbouring nodes interfere with each other. There are two broad types of chain networks, the typical chain network of many transmitters and a spot network of one mobile node using a backhaul such as satellite, a wide area network, an HF radio or a fixed telephone infrastructure.

Typically, the chain network is formed by an infinite number of transmitting and receiving nodes placed at some inter-node distances along a curve. We will use a simplified version where the nodes are placed at equal distances from each other in a straight line. In this case, the network is symmetric around the transmitting node (MoHotS). For communications to succeed at a receiving node, the signal to interference ratio must be higher than an agreed threshold, denoted as S_0. Figure 1 is an example of a symmetric one-dimensional chain network.

In Figure 1, the receiving node (R) experiences interferences from transmitters separated from it at hop distance: $^{\pm k,\ \pm 2k,\ \pm 3k,\ \ldots,\ \pm\ nk}$.

Assume the chain network is carried by vehicles on a highway. Each MoHotS has the capability to relay data from one vehicle to the next until the data reaches its destination thereby form a chain network. For the moment, we will ignore the specifications of the MoHotS and focus on the level of interference experienced by the receiver. The application described is not unique to highways, but is also applicable to chain networks on trains in which routers are either located within the carriages or hybrid versions with some nodes fixed along the tracks. Hybrid versions include when some routers are mounted on mobile carriages and others are fixed on poles along the rail line. In a suburban situation, chain networks can be formed by islands of hot spots relaying data for each other. As more and more individuals deploy wireless local networks (WLAN), islands of communication spots are appearing in cities. For all practical purposes these networks are unconnected and do not aid each other in data relay.

Two things can happen. First, the MoHotS may form a wide area network with coverage areas and with areas that are uncovered. Second, the MoHotS could use hop-by-hop communication to relay data. Issues related to how MoHotS are integrated into existing moving network are interesting areas of research. This paper focuses on the dynamics of the moving network and in particular the extent of uncovered regions and the interference levels when many MoHotS are deployed or form a single network. In practice, there will be islands of coverage and holes and sub-nets will result. The degree of coverage fragmentation can be studied.

3.2. PROBABILITY OF MAKING A CONNECTION

Two MoHotS can connect to each other provided they are within range or their regions of coverage intersect or there is a node within an area that is common to both of them. Consider the situation in Figure 2 where two nodes are located at S and D and the distance separating them is x. If they have equal range coverage r and use omnidirectional/directional antenna, we can deduce the probability that they can connect or not. The probability that there is a node in their area of intersection A is dependent on the size of the area.

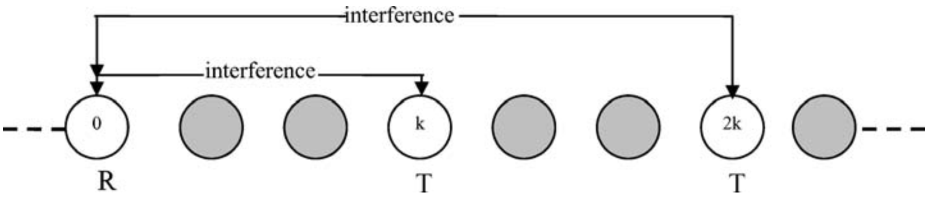

Figure 1. Linear chain network with interfering transmitters.

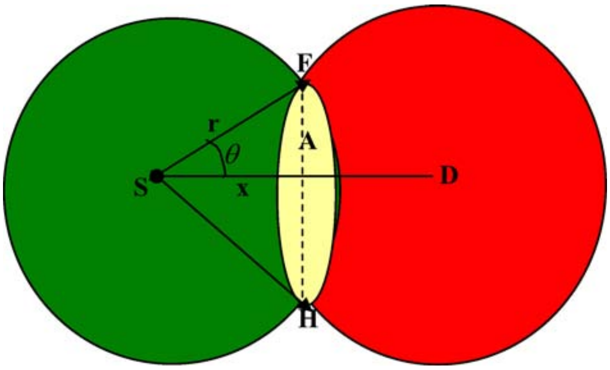

Figure 2. Intersecting areas of coverage of two MoHotS.

Suppose equal contribution to the area A comes from each of the MoHotS and the distance FH = 2h, we can derive an expression for the area A. Since SD = x we have

$$h = r \sin\theta; \quad x = 2r\cos\theta; \quad \text{and} \quad \theta = \cos^{-1}\left(\frac{x}{2r}\right) \tag{7}$$

The area of the sector SFD is equal to the area of the sector DFH. By subtracting the area of the triangle SFD from the area of the sector of the circle SFD we obtain half the area of A. This is given by the following steps. The area of the sector is given as:

$$A_{\mathrm{S}} = \theta r^2 \tag{8}$$

Half of the area of the triangle SFH is given by the expression:

$$T_1 = \frac{1}{2} \cdot \frac{x}{2} h = \frac{x.r.\sin\theta}{4} \tag{9}$$

Hence:

$$A = 2(A_S - 2T_1) = 2r^2(\theta - \sin\theta\cos\theta) \tag{10}$$

Therefore, the intersecting area of coverage is proportional to the sector angle and the radius of coverage or coverage range of the MoHotS. For example, if the antenna on a MoHotS has three sectors so that it transmits along the bore sight (looking to the front of mobile vehicle), also behind the vehicle and lastly across the width of the highway; if the sectors are 120 degrees wide, the maximum intersection area for the sector becomes $A = (\frac{8\pi+3\sqrt{3}}{6})r^2 = 5.055.r^2\,(\mathrm{km}^2)$ and the area of intersecting coverage is directly proportional to the range of the MoHotS. The intersecting region is crucial for two reasons. Handover of calls should take place within this region based on agreed protocol. Also, a receiving terminal in this region hears at least two MoHotS and the signal from the one it is not attached to is the dominant interference. The instantaneous value of area A varies with the relative speeds of the vehicles carrying the MoHotS.

The probability of achieving connections with a number of hops can now be estimated. Let G be the average number of nodes between S and D that are within transmission range to be used as relay nodes. If the nodes are assumed to be uniformly distributed on a highway and nodes can make connections between themselves if the distance between them is x, we can estimate the probability that a connection can be made. To do so we require the density of nodes in the circular area surrounding a node which is given by the expression

$Q = G/\pi r^2$ nodes per unit area. We denote the probability that a node can make a connection with another node at distance x away with a single hop as

$$p_1(z) = \begin{cases} 1; & x < r \\ 0; & \text{otherwise} \end{cases} \tag{11}$$

Therefore the probability that there are no nodes within an area of size A the intersection coverage areas of two neighbouring nodes is

$$p_0 = \mathrm{e}^{-GA/\pi,r^2} \tag{12}$$

Therefore since this probability of making a connection with a station with two hops is equal to

$$p_2(x) = \begin{cases} 1 - e^{-GA/\pi . r^2} & ;\text{when } r < x \\ 1; & ;\text{when } r > x \end{cases} \tag{13}$$

This equation can be used to estimate the probability of making $n - 1$ connections in chain ($n - 1$ hops) from source to destination. This probability is estimated as the probability of using $n - 1$ hops (and not $n - 2$ hops) to reach a station at distance z as: $p_{n-1}(z) - p_{n-2}(z)$.

4. Interference In MoHotS and Chain Networks

Consider a chain MoHotS relaying of data using hop by hop communications. A variant of this network was considered in [1]. For the linear case by aggregating the interference in a receiver as coming from its neighbouring transmitters, the total path loss for this scenario can be estimated [1] as:

$$L_I(dB) = b_d + 10\gamma \log(k.s_d) + 10 \log \left(\sum_{l=1}^{+\infty} I^{\gamma_1} \right) \tag{14}$$

The middle term uses an average path loss exponent in the chain. It assumes that the relaying nodes are equally separated from each other and k is the hop index. It also assumes that the interference comes from an infinite number of neighbouring transmitters. In practice these assumptions must be modified as the relay nodes are unlikely to be equally separated and the number of interfering sources is finite. It has been shown in [1] that the summation in Equation (14) is convergent as long as the path loss exponent is negative and less than unity ($\gamma_1 < -1$). In fact the third term is convergent if three conditions are fulfilled: First the summation may be taken over a finite number of terms. Second, the exponent of the terms in the summation is negative and less than-1. Third, the variable raised to the power of the path loss exponent is less than unity. Therefore, we consider these cases where the path loss exponent is positive and the variable being summed is less than unity and finite terms are used. Such cases relate to practical situations.

4.1. LIMITS OF INTERFERENCE FROM OTHER TRANSMITTERS

Guo et al. [1] have argued that the third term in Equation (14) is only convergent if the path loss exponent is negative and less than unity. For practical purposes, the path loss exponent is positive and more than unity. Even so, we show in this paper that the third term in Equation (14) is convergent in practical situations. In practical situations, the number of interfering MoHotS (transmitters) is finite. Consider N (where N is large) interfering MoHotS and re-write Equation (14) as follows:

$$L_I(dB) = b_d + 10\gamma \log(k.s_d) + 10 \log \left(\sum_{l=1}^{N \to \infty} I^{\gamma} \right) \tag{15}$$

Table 2. Values of converging summation term

	$N = 6$					
γ	0	1	2	3	4	5
$\sum_{I=1}^{N-1}[1+\alpha_1^{\gamma}]$	6	3.500	2.53	2.042	1.755	1.569

This equation shows that the channel is modelled as the product of three independent terms of path loss, shadowing and fading. Let $_{N\rightarrow\infty}$, and ($\gamma \geq 0$), then:

$$L_I(dB) = b_d + 10\gamma \log(k.s_d) + 10 \log \left(\sum_{I=1}^{(N-1)\rightarrow\infty} N^{\gamma} \left[1 + \left(\frac{I}{N} \right)^{\gamma} \right] \right) \tag{16}$$

Let $\alpha = I/N$. Guo et al. have shown that for the case when $I = \alpha_I$, and $\gamma < -1$ the third term in (15) converges to $\gamma/(1+\gamma)$. However, the interesting practical case occurs when the path loss exponent is positive. We will show that as N in the fourth term in (16) increases, the term is convergent. Let

$$L_I(dB) = b_d + 10\gamma \log(k.s_d) + 10\gamma \log N + 10 \log \left(\sum_{I=1}^{(N-1)\rightarrow\infty} \left[1 + \alpha_1^{\gamma} \right] \right) \tag{17}$$

Since generally $\alpha < 1$, the fourth term in (17) converges for all practical purposes. The total interference from all the transmitters is therefore given by the equation:

$$L_T(dB) = 10\gamma \log N + 10 \log \left(\sum_{I=1}^{(N-1)\rightarrow\infty} \left[1 + \alpha_1^{\gamma} \right] \right) \tag{18}$$

The second term in (18) is most dominant when $\gamma = 0$ and decreases rapidly for large values of γ. The bound for large N occurs when $\gamma = 0$ and is 10log*N*.
Therefore

$$L_T(dB) = 10\gamma \log N + 10 \log N = 10(1+\gamma) \log N \tag{19}$$

Figure 3 shows the variation of the limits of interference L_T from other transmitters as a function of the path loss exponent. The number of transmitters is varied from 10 to 1000 and the path loss exponent varies from -4 to $+20$ in steps of $+1.0$ and covers the range of exponents for four environmental domains described in subsequent sections. Clearly, as the value of the path loss exponent increases, losses increase as well. For most practical purposes, the loss exponent is less than 6. Similarly, on a highway, the number of MoHotS within range of each other will normally be far less than 1000. Therefore the interference level will not grow beyond bound. The interesting cases will therefore use the graphs for $\gamma \leq 6$ (Figure 3). Hence, we compute L_T for $N = 6$ and vary the path loss exponent below 6.

In traditional cellular communications, a cell experiences the most interference from 6 other cells in the first-tier of a cluster of cells. Therefore in Table 2, L_T is computed for $N = 6$. L_T decreases rapidly for $\alpha < 1$.

Table 2 shows that this term converges rapidly to 1 as the value of the path loss exponent increases exponentially.

4.2. TERRAIN AND PATH LOSS CONSIDERATIONS

The application of MoHotS is usually out door, indoor or underground. Path loss exponent varies widely across propagation environments. Therefore the bound on the hop distance and number is different for different types of propagation domains. Before the boundary of the short-distance (about 2m for UWB) and long-distance propagation regions the path loss exponent of the path is 2. After this in the long distance region the exponent for out door environments is around 4 except in none line-of-sight situations when it could be bigger than 4. Knowing the path loss exponent of the Molink, the required power levels to use can be determined. The value of the path loss exponent is an indicator of how fast energy is lost between the transmitter and receiver. $\gamma < 2$ is a measure of the guiding effect of the channel and when $\gamma > 2$ the channel is considered to be scattering energy.

4.2.1. *Path Loss Exponents in Different Environments*

The following tables provide typical values of γ and also show how different structures guide radio waves in MoHotS and which ones scatter them. The tables also provide a database of γ for design of wireless networks in different environmental situations.

4.2.1.1. *Out Door Environments.* The value of path loss exponent out doors is a function of the terrain (free space, urban, suburban, rural area and foliage type), if communication is line-of-sight (LOS) or non-LOS (NLOS), height of the antenna and the channel frequencies. Table 3 summarises these effects.

The high value of exponent for dual carriage highway is due to ground reflections from the road surface. The dynamic range of γ in this table is 6.3. None line-of-sight communication often means higher path loss exponents. Similarly the higher the height of the antenna the higher the expected pass loss exponent. The value of the path loss exponent after the break

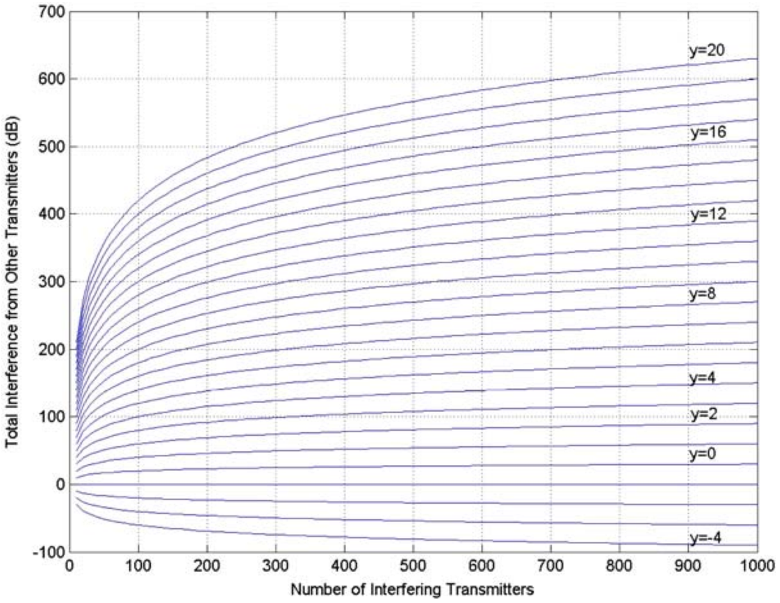

Figure 3. Loss limits as function of path loss exponent (y) and number of transmitters.

Table 3. Path loss exponent for out door environments

No	Location	Path loss exponent	Frequency range
1	Urban	4.2	
2	Free space	2	Micro cellular
3	Log-normally shadowing area	2 to 4	Micro cellular [16]
4	UWB LOS up to breakpoint	2	UWB range
	UWB LOS after breakpoint	4	UWB range
	LOS urban (antenna ht = 4 m)	1.4	5.3 GHz range [5]
	LOS urban (antenna ht = 12 m)	2.5	5.3 GHz range
	NLOS urban (antenna ht = 4 m)	2.8	5.3 GHz range
	NLOS urban (antenna ht = 12 m)	4.5	5.3 GHz range
5	LOS rural (antenna ht = 55 m)	3.3	5.3 GHz range [5]
	NLOS rural (antenna ht = 55 m)	5.9	5.3 GHz range
	LOS suburban (antenna ht = 5 m)	2.5	5.3 GHz range
	NLOS suburban (antenna ht = 12 m)	3.4	5.3 GHz range
6	Highway micro-cells	2.3	900 MHz [8]
	Dual carriage highway	7.7	1.7 GHz
7	BFWA/directional antenna (5.5–6.5 m)	1.6	3.5 GHz [15]
	BFWA/directional antenna (6.5–7.5 m)	2.2	
	BFWA/directional antenna (7.5–8.5 m)	2.7	
	BFWA/directional antenna (8.5–9.5 m)	2.6	
	BFWA/directional antenna (9.5–10.5 m)	3.6	

point is normally greater than the value before the break point. The break point distance can be approximated with the expression:

$$d_b = \frac{4\pi h_T h_R}{\lambda} \tag{20}$$

h_T and h_R are the heights of the transmitting and receiving antennas and λ is the wavelength of transmission.

4.2.1.2. *Indoor Environments.* In Table 4, the path loss exponent for indoor communications across a wide variation of frequencies is shown. The unpredictability of the path loss exponent is demonstrated by the range of values shown.

Communications indoors at various frequencies affect the path loss exponent and the predominant sources of effects are the height of the building (or height of antenna), antenna directivity, LOS or NLOS communication, channel frequencies, types of materials used in the construction of the buildings and the location of measurements in the building. Omni-directional antennas often result to lower path loss exponents compared to directional antennas. This is because, the omni-directional antennas collects signals from many more multipath sources. Building materials of different types lead to different path loss exponents. The dynamic range of γ in this table is 8.8. Measuring γ is therefore required prior to establishing the relay nodes.

Table 4. Path loss exponent for indoor communications

Path loss exponents for indoor environments			
No	Location	Path loss exponent	Frequency range
1	LOS	1.83	802.11a (5.4 GHz)
2	LOS	1.91	802.11b (2.4 GHz)
3	NLOS	4.7	802.11a
4	NLOS	3.73	802.11b
5	Omni/omnidirectional antennas	1.55	UWB [14]
	Omni/directional antennas	1.65	UWB
	Directional/directional – shadow	1.72	UWB
6	Indoor CDMA	1.8–2.2	20 GHz – 30 GHz
7	LOS	1.73	900 MHz
	NLOS	0.48–1.12	900 MHz
	LOS	2.23	1.89 GHz
	NLOS	−1.43–1.47	1.89 GHz
8	LOS (millimetre wave)	1.2–1.8	94 GHz [7]
	Obstructed channel	3.6–4.1	94 GHz
	LOS	1.8–2.0	11.5GHz
	LOS	1.2	37.2 GHz
9	Inside room of a building	0.77	900 MHz [9]
	Inside room of a building	0.44	1.35 GHz
	LOS DECT picocells	−1.55	1.8 GHz [10]
	NLOS DECT picocells	−3.76	1.8 GHz
10	Corridor ground floor	0.70	450 MHz
		0.48	900 MHz
		0.02	1.35 GHz
		−1.43	1.89 GHz
11	Corndor floor 1 of building	1.12	4.50 MHz
		1.02	900 MHz
		0.07	1.35 GHz
		1.46	1.89 GHz
12	Corridor Floor 2 of building	1.79	450 MHz
		1.72	900 MHz
		0.44	1.35 GHz
		2.22	1.89 GHz
13	Indoor 3rd floor of a laboratory	1.3	2.45 GHz [13]
		1.8	5.25 GHz
		1.7	10 GHz
		1.8	17 GHz
		1.7	24 GHz

Table 5. Path loss exponent for underground communications

No	Location	Path loss exponent	Frequency range
1	Underground (train) – front	12.45	465 MHz [6]
2	Underground (train) – rear	9.72	
3	Underground (train) – front	8.58	820 MHz
4	Underground (train) – rear	8.17	
5	Train yard (parallel to track)	2.7	
	Train yard (cross-track)	3.4	
6	Underground Mine	2.13–2.33	2.4 GHz
	Moving train – 140 km track sites	1.5–7.7	320 MHz [12]

Table 6. Effect of materials on path loss exponent

Path loss exponents for different environmental structures			
No	Location	Path loss exponent	Frequency range
1	Engineering	1.4–2.2	0.8 GHz – 1.0 GHz [11]
2	Apartment hallway	1.9–2.2	
3	Parking structure	2.7–3.4	
4	One-sided corridor	1.4–2.4	
5	One-sided Patio	2.8–3.8	
6	Concrete Canyon	2.1–3.0	
7	Plant fence	4.6–5.1	
8	Small boulders	3.3–3.7	
9	Sandy Flat beach	3.8–4.6	
10	Dense bamboo	4.5–5.4	
11	Dry tall underbrush	3.0–3.9	

4.2.1.3. *Underground Environments.* Communications underground such as in tunnels and mines forms a vital component of the overall wireless communication industry. In many countries, tunnels form significant sections of roads, highways and railways. Similarly communication inside mines is a vital support for mining and mineral exploration. Table 5 records typical path loss exponents reported for underground communications. Understandably, low frequency applications are prevalent in this area.

Path loss exponent in underground communications is normally predominantly very high as seen from Table 5 and explains the high drop outs from mobile phones when used in underground roads. This is due to the terrain, the materials used for construction of the tunnels and to some extent the channel frequencies used. The scattering properties of the terrain also affect the path loss exponent. The dynamic range of γ in this table is 10.95.

4.2.1.4. *Unspecified Environments.* The application of MoHotS is not limited to out doors, indoors or underground. The situation of interest determines the location of application. Path loss exponent in other terrains of interest are summarised in Table 6.

Table 6 demonstrates the varying nature of path loss exponent when different types of materials and the terrain types that affect communications are considered. These tables show that there is no universally accepted path loss model for indoor, out door or underground. Path loss model varies, from building to building and from terrain to terrain. Therefore path loss models are approximations for only a few conditions.

4.2.2. *Implications of Varying Path Loss Exponent*

There are several implications of varying path loss exponents and break points. Firstly, different path loss exponents for different propagation environments mean different levels of signal losses as a function of the environment. Therefore, a single path loss expression is never going to be adequate for all situations. The path loss model for many environments must be a multitude of curves with different slopes and different y intercepts. If the path loss is written as

$$L(d) = L(d_0) + 10\gamma \log\left(\frac{d}{d_0}\right) \tag{21}$$

$L(d_0)$ is a constant dependent on intercept point. Write (21) as a linear function as:

$$L = L_0 + m.x \tag{22}$$

Where $m = 10\gamma$ and $x = \log(d/d_0)$. Therefore the slope of this line varies with the variation of the path loss exponent. Its intercept is proportional to the break point of the propagation regime. This leads to the second implication that the intercept point varies with the propagation regime and the frequency used for transmission. This being the case, we can make several general observations. Although indoor propagation is harder to model because of the large varieties of building materials, path loss exponents for indoor applications are generally small. The signal decay rate inside buildings comes from too many sources unlike out doors where the sources of scattering and diffraction are fewer. Therefore indoor propagation models are not in practice linear. In [15] two terms are added to the linear model to account for diffraction and losses from walls:

$$L(d) = L(d_0) + 10\gamma \log\left(\frac{d}{d_0}\right) + \sum_{j=1}^{N-1} W_j + \sum_{j=1}^{M-1} D_j \tag{23}$$

This equation is used when distance d is less than the breakpoint. When d is greater than the break point, the expression becomes [1]:

$$L(d) = L(d_0) + 10\log\left(\left(\frac{d_b}{d_0}\right)^{\gamma_1} + \left(\frac{d}{d_0}\right)^{\gamma_2}\right) + \sum_{j=1}^{N-1} W_j + \sum_{j=1}^{M-1} D_j \tag{24}$$

D_j, W_j are diffraction from corners and losses from the walls and d_b is the break point distance. γ_1, and γ_2 are the mean path loss exponents before and after the diffraction distance.

5. Conclusions

We have in this paper discussed the basics of wide area networks using MoHotS and chain networks. Mobile hot spots, chain networks of hot spots were discussed. We showed how

MoHotS can be used to build chain networks and the benefits of integrated capacity from islands of hot spots. Expressions for common areas of coverage were derived. We also discussed interference from other MoHotS and the expected limits resulting to Figure 3. Based on reasonable assumptions, it was shown that the interference level does not grow out of bounds. The application of MoHotS and chain networks in highways was discussed extensively. The cases for other outdoor, indoor and underground situations were briefly discussed using the path losses expected based on path loss exponents over a wide range of frequency bands. The canonic path loss expression was modified to include interference from diffraction and other transmitters. We showed that for practical situations, the level of interference does not diverge, but is rather tamed by the path loss.

References

1. X. Guo, S. Roy, and W.S. Conner, "Spatial Reuse in Wireless Ad-Hoc Networks", *Proc. IEEE 58th Vehicular Technology Conference*, VTC 2003-Fall, Vol. 3, pp. 1437–1442, 6–9 Oct. 2003.
2. J.l. Agbinya, F. Oyejobi, and B. Etukudo, *Internet Technology in a Nutshell*, Macquarie Lighthouse Press, Sydney, 1998.
3. Federal Office of Corns Joint Venture: "HAPS-High Altitude Platform Stations", http://www.bakom.ch /imperia /md/content/english/funk/forschungundentwickluna/studien/HAPS.pdf.
4. T. Tozer, J. Thompson, and P. Baynham, "UAVs and HAPs", http://www.elec.york.ac.uk/comms/papers/tozer00 ieecol.pdf
5. X. Zhao, J. Kivinen, P. Vainikainen, and K. Kari Skog, "Propagation Characteristics for Wideband Outdoor Mobile Communications at 5.3 GHz", *IEEE Journal on Selected Areas in Communications*, VOL. 20, NO. 3, pp. 507–514, April 2002.
6. Y.P. Zhang, Z.R. Jiang, T.S. Ng, and J.H. Sheng, "Measurements of the Propagation of UHF Radio Waves on an Underground Railway Train", *IEEE Transactions on Vehicular Technology*, Vol. 49, No. 4, pp. 1342–1347, July 2000.
7. A. Kajiwara, "Millimeter-wave Indoor Radio Channel with Artificial Reflector", *IEEE Transactions on Vehicular Technology*, Vol. 46, No. 2, pp. 486–493, May 1997.
8. S.T.A. Chia, "1.7 GHz Propagation Measurements for Highway Microcells", *Electronics Letters Vol. 26*, Issue 16, pp. 1279–1280, 2 Aug. 1990.
9. A. Chandra and P. Chandra, "Attenuation of 900 MHz and 1.35 GHz Signal Inside Room of a Building", *IEEE International Conference on Personal Wireless Communications*, pp. 198–200, 17–19 Dec. 1997.
10. N. Papadakis, A.G. Kanatas, E. Angelou, N. Moraitis, and P. Constantinou, "Indoor Mobile Radio Channel Measurements and Characterization for DECT Picocells", *Proc. Third IEEE Symposium on Computers and Communications*, ISCC '98, pp. 240–245, 30 June-2 Jul. 1998.
11. K. Sohrabi, B. Maniriquez, and G.J. Pottie, "Near Ground Wideband Channel Measurement in 800–1000 MHz", *Proc. IEEE 49th Vehicular Technology Conference*, Vol. 1, pp. 571–574, 16–20 May 1999.
12. M.V.S.N. Prasad and R. Singh, "Terrestrial Mobile Communication Train Measurements in Western India" *IEEE Transactions on Vehicular Technology*, Vol. 52, Issue 3, pp. 671–682, May 2003.
13. D. Lu, D. Rutledge, "Investigation of Indoor Radio Channels from 2.4GHz to 24GHz", Proc. IEEE International Symposium, Antennas and Propagation Society, Vol. 2, 22–27, Vol. 2., pp. 134–137, June 2003.
14. J.A. Dabin, N. Ni, A.M. Haimovich, E. Niver, and H. Grebel, "The Effects of Antenna Directivity on Path Loss and Multipath Propagation in UWB Indoor Wireless Channels", *Proc. IEEE Conference on Ultra Wideband Systems and Technologies*, pp. 305–309, 16–19 Nov. 2003.
15. K.W. Cheung, J.H. Sau, M.S. Fong, and R.D. Murch, "Indoor Propagation Prediction Utilizing a New Empirical Model", *Proc. ICCS'94, Singapore*, pp. 15–19, 1994.
16. T.S. Rappaport and L.B. Milstein, "Effects of Radio Propagation Path Loss on DS-CDMA Cellular Frequency Reuse Efficiency for the Reverse Channel", IEEE Transactions on Vehicular Technology, Vol. 41, No. 3, pp. 231–242, August 1992.

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