On How Instantaneous Path Loss Modeling Is a Need of Internet of Drones Based Intelligent Aerial Infrastructure

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Abstract. Drone technologies have become integral component to a lot of civilian and military applications. Talking of wireless communication, Aerial Base Stations are being proposed to act as relay and/or to provide cellular communications to the ground users. Most of the work has been concentrated to enhance the coverage and capacity of the network by finding the optimal parameters like aerial BS height, power etc. using definite or statistical path loss models. However, no work has been done to analyze the path loss performance of aerial BS ad-hoc network in serving moving ground users aka Place Time Capacity (PTC). A concept of hovering base stations (HANET) has been proposed previously to serve the PTC problem and in this paper, we put forward the need for instantaneous path loss modeling for network situations where both user and BS are itinerant.

Keywords: Drones · Cellular communications · Path loss modeling

1 Introduction

The need for design and development of wireless infrastructure to serve the massive capacity with high data rates as high as 1 Tbps for the state-of-the-art 5G networks and beyond explains an upgradation of the existing wireline infrastructure. A key challenge for telecom operators has always been serving hotspot areas that are densely packed by potential subscribers. Large subscriber base trying to access the radio resources at the same time is a major cause of network congestion leading to connection failures. Nonetheless, when such subscribers move in a group attempting to use mobile internet concurrently at events like festivals, carnivals, etc., they tend to create capacity demand at every position they traverse. Ambuj et al. have termed this condition of moving hotspot, even more precisely capacity-in-motion with respect to time as Place Time Capacity (PTC) [1, 2].

As reviewed in [3] and [4], adding low power Pico nodes have been proposed to be a promising proposal in enhancing network coverage and capacity to meet the high user traffic and data rate demand. However, under PTC situations, deploying small pico base stations does not seem to be an appropriate solution as capacity in demand is erratic and

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tend to cease with time. Moreover, the number of handovers might increase posing a burden to the pico base stations. PTC congestion does not occur all-round the year and adding permanent base stations will be under-utilized at all other times.

Internet of Drones or IoD, which is a term dedicated for the integration and synergy of two independent technologies, which are Internet of Things, or IoT, and Unmanned Aerial Vehicles, aka Drones has been suggested into variety of applications [5]. One of the application of Aerial base stations are being considered in providing effective network coverage to ground users during emergency and disaster recovery situations and to serve the traffic hotspots. Recent trends in UAV based applications indicate in employing autonomous small aerial based radio nodes as a solution to assist the existing fixed infrastructure to provide cellular services to the ground users [6, 7]. Exploiting the current advances in compact physical structures, mountable small radio equipment along with small antenna array and accurate sensors are making it feasible for the aerial cells to communicate reliably with the ground nodes. We believe that deploying such multi-UAV radio devices working in teams can greatly solve PTC congestion in countries with potentially dense subscribers, e.g. India.

To service the moving subscriber groups aka Place Time Capacity (PTC) [1] a solution has been suggested in [8] had put forward the need for self-itinerant intelligent radios as a team of swarm intelligence based hovering base stations that were coined in as Hovering Ad-Hoc Network (HANET) that will be elaborated in the next sub-section.

When utilizing the low-altitude aerial vehicles, a consideration must be given to the signals travelling in multipaths due to the obstacles that can appear between the transmitter in the air and the receiver on the ground [9]. In this paper we attempt to explain the need for the analysis on the multipath propagation of Air to Ground (A2G) signal transmission.

1.1 The HANET Architecture

A Hovering Ad-hoc Network (HANET) is a network of aerial radio nodes that collaborate and coordinate to serve accumulated PTC situations at the AoE [10]. To understand the working of HANET, Fig. 1 depicts a conventional network architecture with an AoE served by two conventional base stations (following a PTC congestion and overloading), BS1 and BS2. The modified architecture will comprise additional elements that are:

(1) HANET Members
(2) HANET Gateway Base Station (HGBS)

The flying HANET members that include HANET Serving Members (HSM) and/or HANET Relay Members (HRM) is defined under HANET Base Station Subsystem (HBS) and is a separate network subsystem other than conventional Base Station Subsystem (BSS) involving the overloaded Base Stations BS1 & BS2. A team of HRM that are connected to a HGBS form a HANET Relay Subsystem (HRS). The role of HSM is to provide service to the mobile users underneath and the HRM are used to relay user data from HSM to HGBS. Each HANET member is capable of being a part of either HSM or HRM or both.

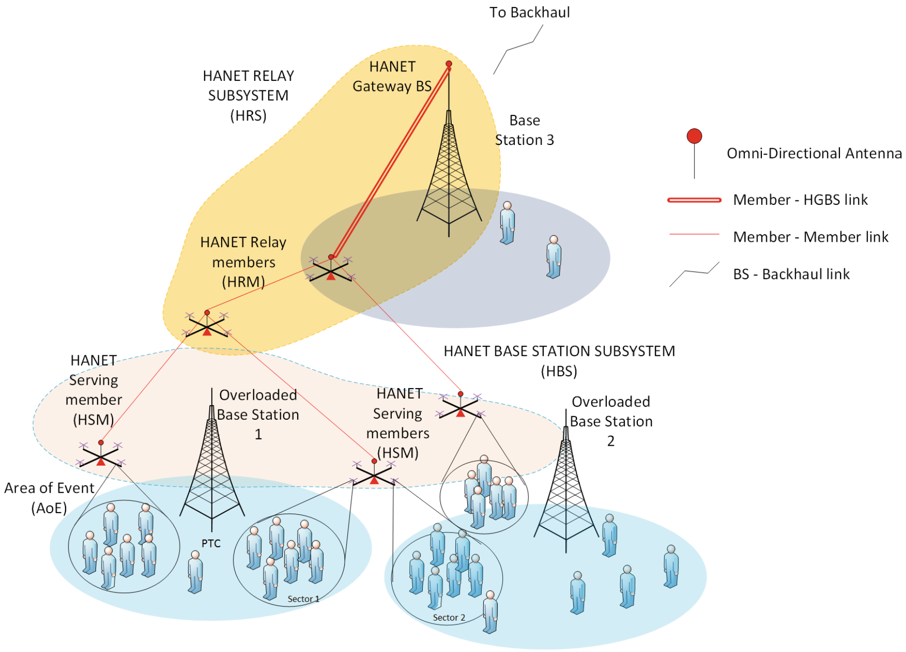

Fig. 1. The HANET architecture

Each HANET member will service the subscribers using four sectors comprising of directional antennas. As we can see from Fig. 1, the four sectors are mainly taking advantage of the proposed HANET design with a quadcopter base with four arms. Covering these arms with aerodynamic carbon-based casing will provide sufficient room for sticking metallic wafers to form a directional antenna and therefore, we can have four directional antennas for each of the technology (IMT and MM). Further, having more sectors per 360-degree span will provide better control on the dynamic subscriber movements in the HANET member's vicinity. Also, the higher number of sectors will provide the opportunity to increase the antenna gain by narrowing the beamwidth without losing coverage at the sector boundaries. Depending on many propagation related factors, more sectors will likely also give us better confinement of interference in the system.

In dense urban, urban and suburban scenarios, it is inevitable to face severe propagation loss due to shadowing, diffraction, reflection, etc. Therefore, direct backhaul from HSM may lead to loss of communication. In this case, the HRM can relay the user data to the nearby base station (HGBS). The communication in the HBS requires member to user communication that will be provided through IMT channels and possible future millimeter wave cellular channels by the HSM. User data will be relayed by the HRM to service the moving crowd continuously. By making HANET follow the moving subscribers, the number of handovers that could have possibly occurred in the network otherwise would eventually reduce thereby potentially relieving the bulk handover issues within the overloaded network. Further, the backhauling will be done through millimeter wave channels only. The member to member control information containing their placement coordinates, IDs, etc. for maneuvering control and optimal positioning of each member will also be communicated through millimeter wave channels.

For our research, we particularly delve into laying mm-waves for a member to member/HGBS and member to mm-user devices as an overlay to traditional IMT layer. This is because (i) no interference with any of the IMT channels, (ii) higher bandwidth to serve mm-user devices and for relaying user data to the nearest base station (both IMT and mm data), and, (iii) member to user communication likely to be in LOS at all times as HSM will be closer to the users underneath. The HSM might not be necessarily in LOS with the HGBS, which is why HRM forming a network chain will come into play to relay the user data from HSM to HGBS.

2 Previous Work in A2G Path Loss Modeling

In [11–13], the authors validate that Air to Ground channels have high LOS probability and lesser shadowing and path loss in NLOS over terrestrial links to provide better coverage with By now, airborne ad-hoc networks have been studied to improve connectivity [12, 14], to optimize mobile networks in overload and outage situations [15] and to enhance the cell capacity [16, 17]. In [18], some field measurements were conducted LTE 800 MHz frequency band, using a commercial UAV and their results show that path loss exponent decreases as the UAV moves up, away from the ground.

It is essential to model the Air to Ground propagation channel by accommodating the path loss effects and shadowing due to ground obstacles. Statistical path loss models for urban environments were defined in [11] and as a part of ABSOLUTE project in [19], where the path loss and shadowing were evaluated as a function of elevation angle. The ABSOLUTE project also investigated on the optimal altitude of Low Altitude aerial Platforms (LAPs) to provide maximum radio coverage [14]. Their study showed that optimal altitude is a function of maximum allowed path-loss and statistical parameters of urban environment by considering a fixed value of 10 dB for maximum allowable path-loss for their analysis.

Optimal altitude of drone small cells [20] was examined based on path loss analysis performed in [16]. Cognitive relay nodes to improve the coverage of airborne LTE emergency network were also proposed [21] considering the path loss models defined in [7] and [19]. Authors in [21] considered standard models like Okumara-Hata, COST-Hata and COST- WI propagation models for evaluating the coverage of UAV wireless networks to provide cellular services. Further the authors in [22] have extended the Rice channel model to account for multipath effects introduced by the flight altitude of UAVs using the IEEE 802.11 communication link. In [23], authors have proposed a method to apply approximately the multipath channel models of terrestrial broadcasting in UAV based broadcasting.

The work aforementioned used an invariable path loss model and/or definite value of mean path loss for their analysis. In this paper, we direct our investigations to the instantaneous path loss modeling wherein the UAV mobility plays a significant role in transmitting signals to the ground receivers.

3 Instantaneous Path Loss Modeling in HANET

Any existing Path Loss Model (PLM), which is primarily static in nature, can be perceived as the instantaneous path loss model (iPLM) if the system dynamics are taken into account and the eventual value of the iPL is time dependent and time variant. Such PLMs are inevitable for non-conventional approach of the network deployment and network architectures.

3.1 Need for IPL Estimation

As the HANET comprises of hovering base stations to follow and serve PTC groups, because of their movements, different physical morphologies and RF signal characteristics might be encountered. Each member hovering to different positions with time across the Area of Event (AoE) will observe variation in land morphology like buildings, open spaces, trees, water bodies, etc., on the ground that constitute the AoE along with the PTC subscribers.

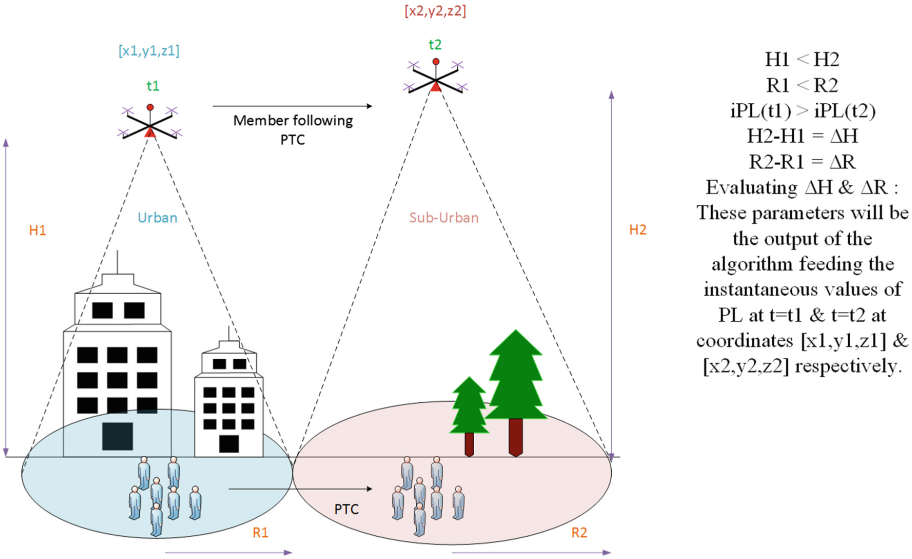

Fig. 2. Variation in the physical environment due to time dynamics

As depicted in Fig. 2, to follow a PTC group, the HANET member needs to displace itself from coordinate [x1, y1, z1] at time t1 to coordinate [x2, y2, z2] at time t2. At t1, the physical terrain observed by the member was urban and is it hovered, the environment observed by the member at time t2 was sub-urban. It is evident that with change in physical environment, the maximum allowable path loss will also differ. This change in path loss due to physical land morphology computed at different time instants is called as the *instantaneous path loss (iPL)*. Computing with the new iPL value the member will move to a new position and transit its altitude from H1 to a new altitude H2 to deliver the required performance. With the change in altitude eventually the coverage radius will also vary. The increase or decrease in height from the previous position will be governed by the ground physical morphology encountered.

3.2 Estimation of IPL by HANET

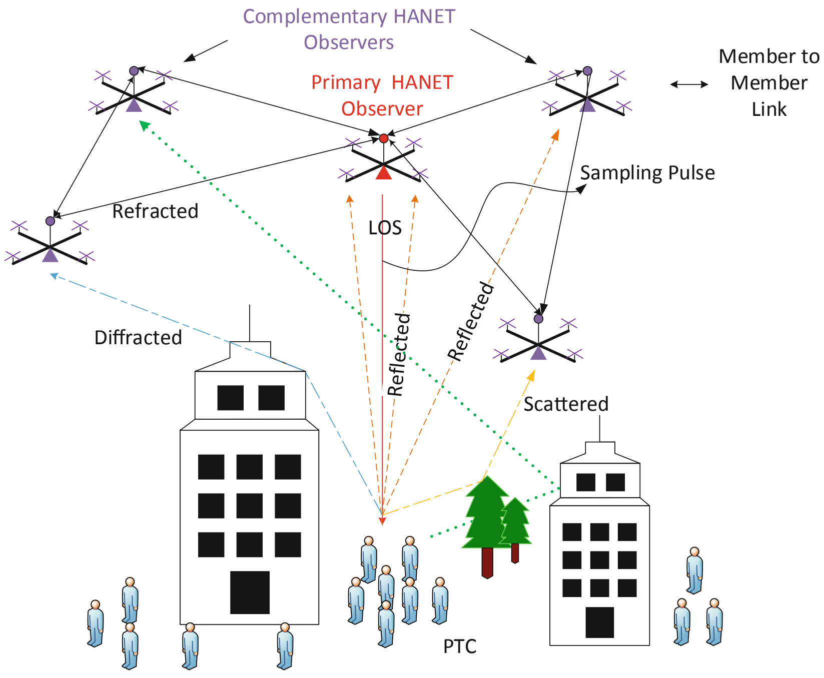

Fig. 3. iPL estimation by the HANET members

Figure 3 depicts the concept of HANET model to obtain the iPLM through sensing the land morphology in real time. The figure shows two groups of HANET member observers, primary and complementary, that collectively determine the iPLM for a given network situation. The primary observer sends a pulse that will bounce back to antenna arrays fitted in the chassis of the member and is responsible for the majority of sensing. However, it can be assisted by complementary observers with the role of sensing the reflected, refracted and diffracted signal spread of the sampling pulse that could be used to determine the signal fading of the AoE. The HANET members are low altitude serving BSs with inter-member distance approximately >300 m, the presence of such complementary members nearby is quite likely. Hence, neighboring members, whose primary job is to serve the user clusters beneath, might help the primary observer to estimate the losses in the area beneath it. Eventually, these members can help each other by swapping the responsibilities and to estimate the iPL for a significant land area where the user clusters may traverse. Needless to say, more are the neighbors, more efficient is the path loss estimation. Since, the very concept of this HANET model is to work cooperatively as a team, this kind of real time estimation of the path loss can help in enhancing the coverage and capacity of the system.

3.3 Challenges in Formulating IPL by HANET

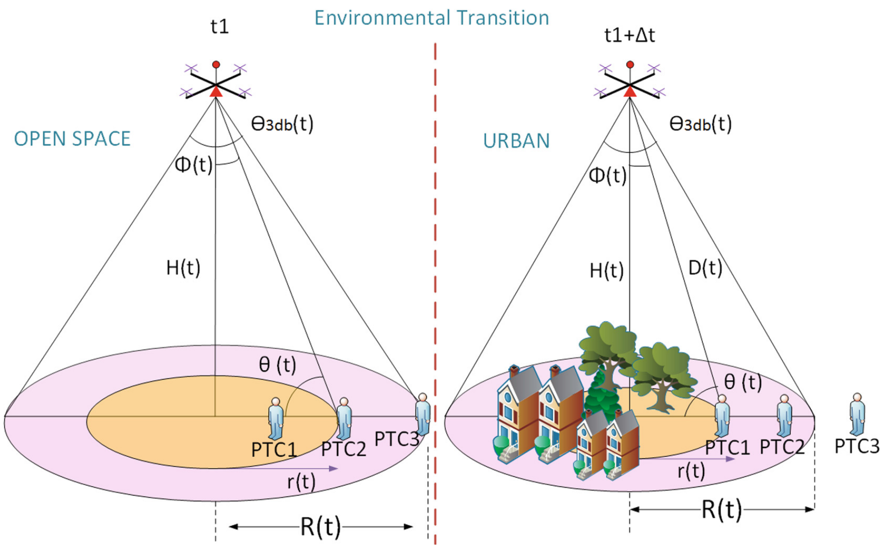

Fig. 4. Dynamics due to environmental transition

The innovative architecture, discussed in this paper, composed of hovering base stations is what we define as A Self-Itinerant Intelligent Aerial Radio Architecture (SIIARA). This SIIRA model, consisting of multiple HANET members will be efficient when all the participating members are well coordinated and placed as per demand. It is proposed that members use a separate channel to communicate with each other to itinerate and configure according the environment beneath each of them. It is also expected from this architecture to proactively predict and follow the user cluster thereby, creating a jittery signal reception for users below the transiting member due to variant morphology across the path that each cluster follow. Figure 4 describes such situation by exemplifying a single member that is in transit. We can see in this figure that from any arbitrary time t1 to a next time instant t1 + Δt, there can be significant variation in the morphology beneath a serving member as it itinerates (here from an open space such as park to an urban type house cluster). Such jitters, when occur unexpectedly, may cause severe disruptions in the member-member relations and configurations time to time. Hence, the parameters that relate coverage radius (R), member height are likely to vary with time. Although, each parameter here are variables themselves and can accommodate the changing values, however, when morphological variations below a member are function of time, then incorporating them in modeling the relations will provide more convenience in configuring a SIIARA network.

The A2G radio access channel between a HANET member and a subscriber group beneath will accommodate variable physical characteristics at any given time. In Fig. 4, we present a case where PTC groups move from one place to another from a given initial condition at time ‘t1’. Here we represent the PTC groups as single users. The initial conditions observed an open space terrain and certain values for the altitude of the member, transmit power, distance between transmitter and receiver, throughput etc. such that all three PTC groups fall in the service of the member above them. At ‘t1 + Δt’, the PTC groups traversed the member also displaced itself. The terrain now observed was urban and in order to deliver the same performance the HANET member will have to change its altitude and come closer to the ground. By doing so the footprint has also decreased and now the PTC3 group is outside its service area and this needs to be communicated to the neighboring members to adjust their own parameters to accommodate the left-out group.

An important consideration will be in using a single-lobe antenna, with its boresight orientated in the vertical direction towards the users as mentioned in [8]. The normalized gain pattern (with a maximum gain of 0 dBi) for a single-lobe symmetric beamwidth antenna can be approximated as,

$$G_r = \cos^m \Phi \tag{1}$$

Where Φ is the angle with respect to the boresight, with a range from 0 to $\pi/2$; and m can take integer and non-integer values. Further,

$$cos^m \left(\frac{\theta_{3db}}{2} \right) = 0.5 \tag{2}$$

Θ_{3dB} is the half-power beamwidth (HPBW);

The users within the half power beamwidth shall receive the maximum power with decrease in power when moving away from it. While user group is moving the member following it must ensure to accommodate majority if the users within the half power beamwidth. The top to bottom approach of illuminating the challenge area is more feasible than any other probable methods, as this leads to line-of-sight convenience between user and the serving base station.

In case of iPLM, the beam width estimation must include the system dynamics and the augmented equations shall not be as simple as Eqs. (1) and (2). With every iterative move that the users groups on the ground take, there an entire new PLM scenario that the HANET members have to take to cater of new situations. This also includes changes in the propagation environment, user densities, deployment feasibility and many more. Hence, proactive knowledge of the iPL is inevitable for the drones for network coverage solutions.

4 Conclusions

This paper is an attempt to put forward the need for modeling the path loss between an aerial vehicle serving as base station in the air and the ground receivers which are the cellular users. Because the serving base stations are in mobility at all times and target to serve the moving user groups on the ground, we suggest that the path loss should be taken into account depending on the physical and land morphology that might change in mobility-driven scenario. We have coined this concept as *instantaneous path loss (iPL)*. We present the need for the same and discuss the challenges in formulating the instantaneous path loss modeling where Internet of Drones based intelligent aerial infrastructure is used to service the ground users.

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