# Capacity and Link Budget Management for Low-Altitude Telemedicine Drone Network Design and Implementation

Bernard Fong, A. C. M. Fong, and Kim-Fung Tsang


## Abstract

Network planning involves link budget and capacity management to ensure scalability since adequate capacity is necessary to support coverage expansion and traffic demand increases. The primary objective in network standardization is to minimize implementation costs while maintaining a desired level of service. The harsh outdoor environment of millimeter-wave propagation is subject to various uncontrollable factors that can significantly affect network performance and reliability. This is particularly problematic for drones that support life-saving telemedicine applications, especially when many accidents take place under heavy rainfall, making standardization particularly challenging. Our study compares a number of deployment options such as variation of modulation schemes and differences of carrier frequencies between 10, 30, and 50 GHz. The selected frequencies cover a broad range of options for 5G implementation that serves as a backbone network for standardizing communication networks for mission-critical telemedicine drone services.


## Introduction

5G cellular networks support numerous multimedia services and applications such as telemedicine and multimedia streaming. In many parts of the world, 5G networks operate across the 24–50 GHz millimeter-wave (mmWave) spectrum [1]. Various frequency bands are available for deployment in different parts of the world; the selection of carrier frequency depends on spectrum allocation by local authorities and operational conditions primarily determined by population density and rainfall statistics.

Numerous healthcare and medical services heavily depend on 5G communication systems with a high degree of reliability and availability [2]. Although multipath generally is not a significant factor due to short paths as high gain antennas with narrow beamwidth can be used, system performance is greatly affected by link availability due to atmospheric conditions and the requirement of line-of-sight (LoS) or near LoS to be established between antennas [3].

While 5G offers numerous advantages over previous generations of cellular networks for supporting telemedicine services, data transfer is often carried out in the harsh environment subject to numerous causes of signal degradation and atmosphere phenomena such as interference, rain-induced attenuation, and depolarization at these frequencies. Frequency planning for an allocated spectrum uses multiple-sector systems with each sector supported by a base station with localized coverage serving a microcell site typically with a size of less than 1 km. The impacts of cell-to-cell interference therefore warrant further studies for network optimization.

In addition to interference, a number of degradation factors can also severely affect network management since the network deployment in an outdoor environment will be subject to various uncontrollable conditions. Influential factors such as rain-induced attenuation must be considered to ensure adequate network availability, particularly in situations where the network supports critical life-saving missions. Network capacity planning ensures efficient use of available bandwidth within a certain budget.

The specific problem associated with each system may differ; the corresponding set of problems related to planning and optimal solution to that problem can be obstinate. Realizing these problems, research has been conducted that leads to proposals for solving survivability for communication networks [4, 5]. Following these studies, we investigate issues associated with 5G network backbone deployment for optimization management. To maintain scalability, an existing system providing network coverage for a group of subscribers requires further improvements to serve a growing number of customers or to provide a wider range of services, while some room for network expansion can be accomplished by using techniques such as frequency reuse and selection of modulation scheme [6].

This article outlines factors that affect network implementations by focusing on studying the effects of co-channel interference and attenuation due to rainfall in order to optimize network capacity through scalability [7]. The study of interference and rain attenuation issues allows a network to be optimized for support a wide range of wireless telemedicine applications outlined in [8] so that appropriate standards can be set based on these optimized parameters.

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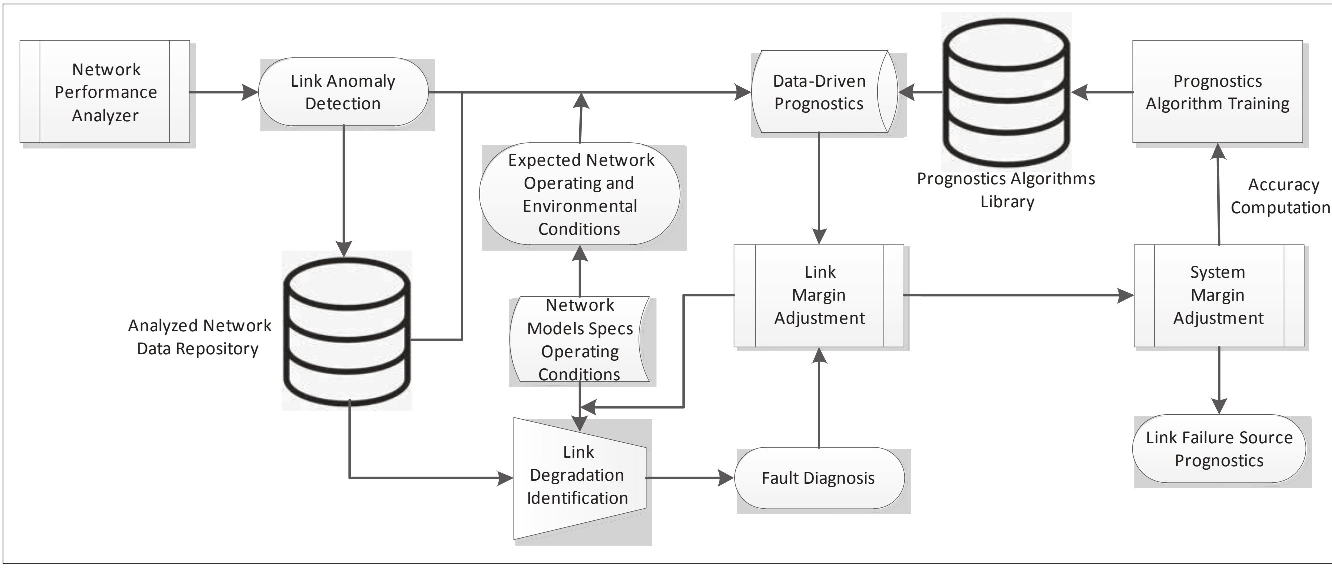


**FIGURE 1.** Physics-of-failure-based self-cognizant network model.

## SYSTEM DESIGN AND IMPLEMENTATION

To carry out actual measurement, we use a broadband wireless access (BWA) network for our study with system parameters as follows: antenna gain of the transmitter and receiver is 18 and 28 dBi, respectively; receiver sensitivity is −81 dBm with a sub-channel bandwidth of 12.5 MHz. This forms the network backbone suitable for serving a low-altitude telemedicine drone that serves remote areas. From a communications standard's perspective, we concentrate our discussion on the network segment that serves as gateways to the hospital system from accident and emergency (A&E) support with a direct connection to the telemedicine network backbone. A service node contains centralized switching and routing equipment so that a hospital can simultaneously link to multiple drones.

The drone has an array of directional antennas with low beamwidth mounted with direct LoS to a base station so that a point-to-point link established for the drone to communicate with the base station. Highly directional antennas with low beamwidth are therefore used. 5G microcell sizes are relatively small compared to the existing 4G LTE cell coverage area that poses capacity constraints and placement of antennas on the drone, certain restrictions are imposed on the location of drones in relation to the base station [9]. Low-altitude drones usually operate in a harsh environment, and wireless links are subject to degradation due to varying uncontrollable atmospheric phenomena.

To combat different degradation factors, a self-cognizant telemedicine system as shown in Fig. 1 is deployed to dynamically adjust system parameters such as transmission power, gain, and link and system margins to optimize operational reliability during drone operation. This self-cognizant diagnosis and prognostics integrate network health management into dynamically adjusting link and system margins when the network conditions degrade.

This diagnostics methodology in optimizing reliability in low-attitude drones applies a multivariate network monitoring approach to the extracted features associated with network operational parameters including projections, transformations, and metrics statistics such as centroids that analyzes the correlations among feature parameters to detect changes in operating and environmental conditions like terrain and weather both efficiently and accurately. Changes in metrics that are indicative of network faults or degradation are the precursors to failure and used to make diagnostic decisions pertaining to the health of the network in real time. Time series data of the extracted features is modeled with prognostics algorithms to make future decisions regarding the health state of the network. An inference framework for classification and regression of the feature data to moderate the prognostic and physics-of-failure predictions in line with posterior distributions that assign overly high confidence to the estimated class memberships of the feature patterns. Forecasting models are constantly updated for prediction of multivariate time series data with strong correlations and periodic systematic patterns. The self-cognizant system then evaluates the algorithms and the overall diagnostic and prognostic accuracy from previously known abrupt faults and failures as well as network operational data. Features associated with network reliability include the presence of link outage and intermittent failures such as interference and rain-induced attenuation, highly correlated parameters, and the masking of faults and failures due to the large multivariate and multidimensional characteristics of the network data.

For healthy drone networks and mission profiling, the system uses Gaussian mixture modeling, which is a weighted sum of Gaussian density functions that is used to approximate probability density functions of a healthy network and to classify prognostics algorithm training data before it is matched against input stimuli. The use of density functions enables the system to address any uncertainty that is caused by uncontrollable factors such as electromagnetic interference, harsh terrain, and rainfall. This mixture

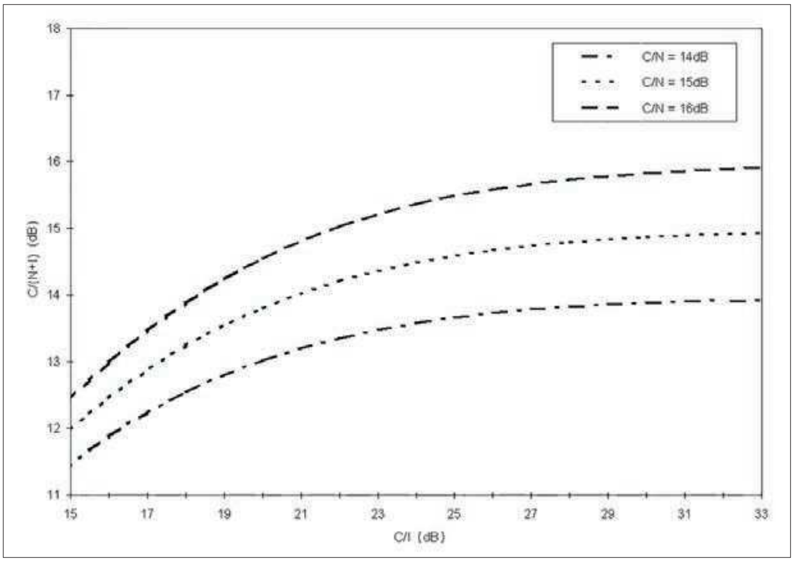

**Figure 2.** Carrier-to-noise ratio.

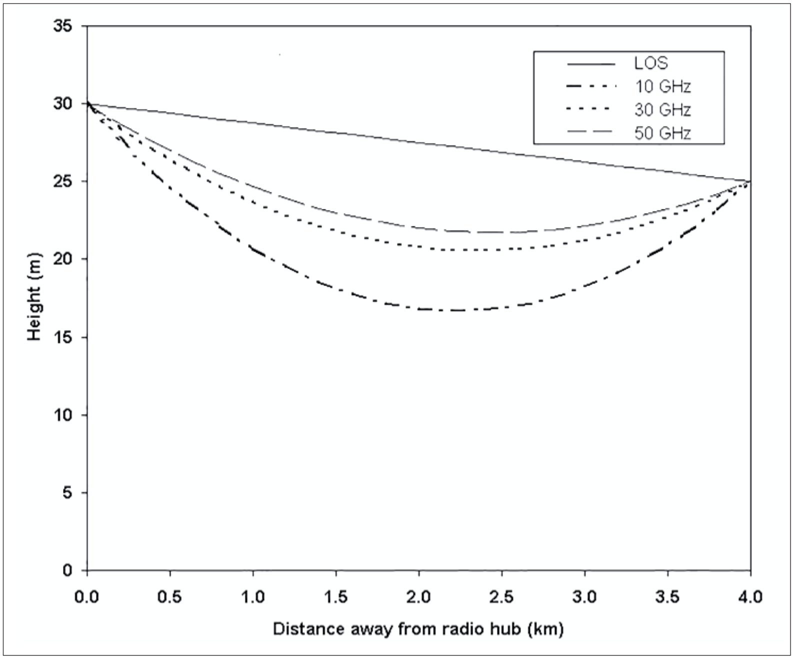

**Figure 3.** First fresnal zone clearance.

method facilitates modeling of highly nonlinear behavior over the changing state of the network, as well as past behavior experienced by the drone while operating in the same area. Using the Expectation Maximization (EM) algorithm allows computation of estimates for the probability distribution for the network parameters and their statistical parameters such as standard deviation, kurtosis, skewness, and ramp rate; this reduces the data content and enables seasonality and cyclic behaviors to be analyzed for adjusting the link and system margin.

In addressing link outage and intermittent failures that could severely impact the operational reliability of telemedicine drones, the system utilizes unsupervised learning methods of self-organizing maps, and Bayesian clustering to optimize the prognostics algorithms as well as carrying out network anomaly detection through statistical process control and environmental monitoring.

## Planning and Capacity Management

Two separate channels are assigned for different traffic directions. The downstream channel usually has higher data throughput than that of the upstream, so co-channel interference of the downstream is a more severe problem than that of the upstream. In order to reduce the co-channel interference, orthogonal frequency-division multiplexing (OFDM) is normally used for the purpose of reducing co-channel interference [10].

First, we investigate the extent of carrier-to-interference ratio (C/I) that degrades carrier-to-noise ratio (CNR or C/N). Cross-polarization discrimination (XPD) affects the use of frequency reuse schemes with channels of orthogonal polarization, XPD of approximately 15 dB for frequency diversity between sectors without cross polarization has been reported [11]. We evaluate the C/(N+I) interference in Fig. 2, which shows that a CNR loss of 0.5 dB is caused by 23 dB C/I. In most cases, frequency reuse by sectorization increases network capacity; the loss in cell coverage with alternating polarization deployment results in approximately 96 percent of the hub coverage area is not affected by cell-to-cell interference. To reduce the area affected by interference, sectorization into 30° and 45° are considered such that sectorizing into 30° allows sectors to be split one at a time, whereas two neighboring sectors must be split at the same time with 45° sectors in order to maintain frequency diversity and target C/I. The signal error rate (SER) of using higher-order *M*-ary quadrature amplitude modulation (QAM) would provide noticeable improvement in both network performance and coverage area in the expense of requiring a more complex receiver structure.

## Propagation

Height restriction is often imposed in urban areas where maintaining an unobstructed path for LoS may be virtually impossible. Figure 3 shows the variation in radio hub distance for first fresnal zone clearance where there is an increase in demand of foliage clearance as the carrier frequency increases. It shows that at least 10 m clearance is necessary to avoid disproportionate loss. To investigate the effects of blockage further, we study the effects of foliage in Fig. 4, which shows very significant variations in [12]. At 10 m depth, 50 GHz signal exhibits over 20 dB loss. Efficient use of network capacity can be realized by frequency reuse that can be accomplished by a combination of frequency diversity and cross polarization between sectors.

As frequency reuse is greatly influenced by rain, it is important to study the effect of rain attenuation by comparing the loss of horizontal and vertical polarization signals verses rate of rainfall. Best-fit lines of long term statistical results for point rainfall attenuation at the three frequencies of interest are plotted in Fig. 5, which shows the difference in attenuation experienced by horizontal and vertical polarization signals differ more significantly as the frequency and rate of rainfall increases. Such difference can exceed 6 dB when 50 GHz signal propagates under heavy rainfall. Rain has fairly small impact on 10 GHz signal as horizontally polarized signal only attenuates by 4 dB/km when the rain rate approaches 110 mm/h, which usually only occurs in tropical regions of reasonably short duration. The effective path length that relates to the corresponding rainfall rate and actual path length can therefore be computed such that link margin can be dynamically adjusted when needed [13]. These experimental results can be used to derive the link and system margins based on [14] where the system fade margin is more for horizontal polarization than that of vertical polarization. Excessive loss is experienced by 50 GHz carrier under the influence of rain.

## Coverage Analysis

The amount of cell-to-cell interference can severely affect system operation such that the coverage area can be substantially reduced. This can lead to an increase in the required signal power level which differs by polarization due to the fact that signals of horizontal polarization are more prone to coverage area reduction. One of the most important issues concerning reliable operation of low-attitude drones operating in remote locations is to remain within the coverage area. In the context of optimizing reliability for low-attitude drone operation, single-carrier modulation is preferred over multicarrier modulation such as OFDM due to noise immunity and power efficiency.

Since higher-order modulation schemes are more prone to severe cell-to-cell interference, we evaluate the performance of different modulation schemes by assessing the network performance using mean squared error (MSE) estimation as plotted in Fig. 6, which shows that 64-QAM performs best as expected, given the trade-off between spectral utilization efficiency and receiver structure complexity [15]. Each augmentation of modulation scheme doubles the bandwidth efficiency while increasing the power backoff by 2 dB and C/N increases by about 6 dB. We also compare different deployment options with different modulation schemes and deployment options from 4 to 16 sectors with reference to quadrature phase shift keying (QPSK) 4 sectors, which is the simplest deployment option for an omnidirectional coverage. The graph shows the relative coverage areas in logarithmic scale since there is a very significant reduction caused by adequate margins allowed for rain attenuation. Finally, we compare the relative coverage areas for Rain *Region D* as defined by the International Telecommunication Union (ITU) where the impact of rain is minimal as the point rain rate is expected to be less than 20 mm/h. Again, we compare the coverage relative to deployment with QPSK 4 sectors. The reduction in coverage area with higher frequencies become much more significant at higher frequencies. At 10 GHz, coverage is far less affected by rain, while multipath is a far more severe issue.

## Conclusions

A number of factors that affect network scalability have been studied for three different carrier frequencies that span across the operating range of 5G design and implementation. These results can give some insights into necessary link margins for system planning as a vital metric for setting appropriate standards for low-altitude telemedicine drones. The effect of rain on a coverage area is far more significant at higher frequencies, and we have also computed the severity of C/I on sector boundary with or without XPD and system fade margins necessary for maintaining 99.999 percent availability for life-saving critical telemedicine applications. The effect of foliage is also an important consideration as a 10 m depth results in excess of 20 dB loss at high frequencies. All these would have a substantial impact on defining applicable standards for implementing low-altitude telemedicine drone networks.

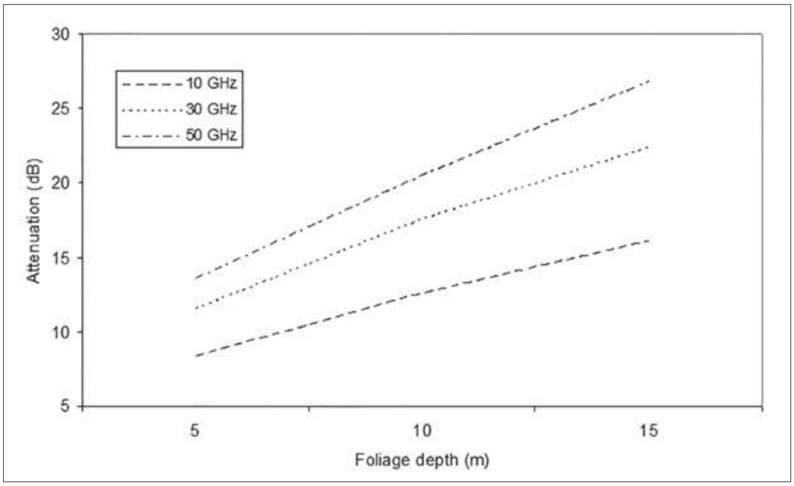


**Figure 4.** Foilage attenuation.

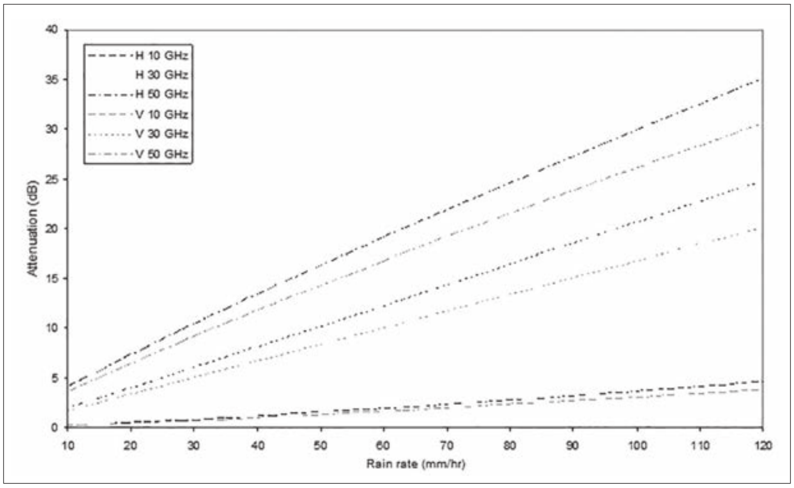


**Figure 5.** Rain attenuation.

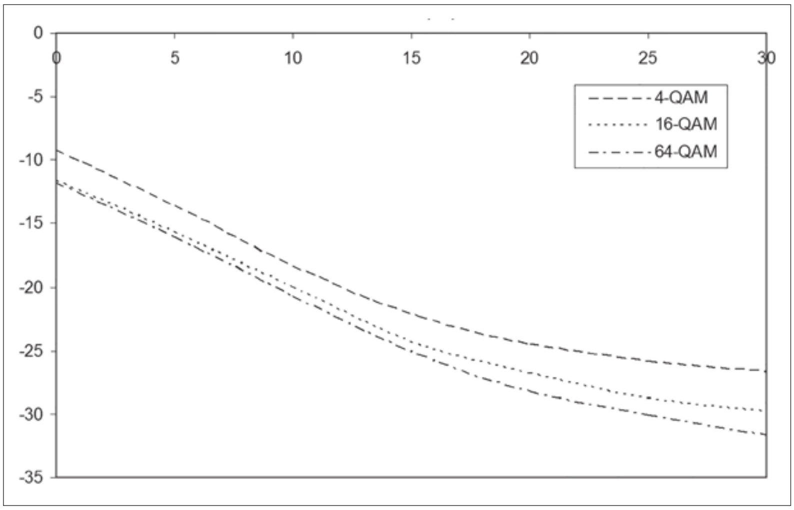


**Figure 6.** Performance evaluation.

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