Cellular Network and its Relevance for Unmanned Aerial Vehicle Application in Malaysia

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Abstract. Range of operation is one of the main limitations in the operation of Unmanned Aerial Vehicle (UAV). The ability to exploit currently deployed data-based cellular network for UAV application enables better utilization of UAV for various applications. Understanding the requirements of UAV application allows the identification of challenges to obtain coverage offered by terrestrial-based cellular networks. This paper outlines the challenges and identifies the relevance of cellular based UAV application in the context of Malaysia as well as its potential application. The main challenges highlighted include the design of cellular network which is optimized for terrestrial users. Additionally, in the context of Malaysia, the tropical weather imposes a further challenge to the reception of reliable radio signals. It has been identified that provided that these challenges can be overcome, the cellular based UAV can benefit the agriculture, security and utility sector in Malaysia.

1. Introduction
Previously, electric-powered UAV are limited to short distance flight due to the limitation on its battery. Recent improvement on battery technology has enhanced its flight range and duration. Today, with an optimized propulsion system, flight range of over 100 km can be achieved. With the extended range capability, the next bottleneck for flight range is data communication range between the ground control station and the flight vehicle. Current consumer system available on the market however, with its actual communication range is limited by transmitter radiated power and is not more than 15 km [1]. Various solutions have been explored such as increasing transmitter power, improving antenna design and using satellite as communication system.

Currently, UAV fly utilizing a direct radio link with the pilot ground station. The reliability in unmanned system is very important [2] and this is potentially achieved by the increased coverage of cellular network. It has been made possible for a remotely situated pilot at an operation centre to launch, fly and land a drone that has cellular network coverage, including in urban areas where structures can obstruct radio communications. This telecommunication network is able to transmit control and telemetry data of the UAV thus allowing an enhanced line-of-sight (LOS) flight [3].

The advantage of using the cellular network as a high bandwidth data-link provides virtually unlimited range which increase the operational range for many applications such as surveillance, delivery, search and rescue and emergency response flights in both urban and rural areas.
Figure 1. Cellular based communication system offered by XBStation.

Today’s cellular networks are, however, not designed for aerial coverage, and deployments are primarily optimized to provide good service for terrestrial users [4]. Another limitation of this method however, is the cell tower coverage. For this technology to be successfully being used in Malaysia, the area coverage and the limitation due to geographical feature needs to be further investigated.

The communication between the ground station and the flight vehicle is best described by Figure 1 which shows the data connectivity by using system offered by XBStation [5].

The organization of this paper are as follow. Section II discuss the needs and requirements for UAV application. Section III describes in detail the challenges in propagation environment imposed on cellular based UAV. Section IV address the potential application of cellular based UAV in Malaysia. Lastly, Section V presents the conclusions of this paper.

2. Needs and Requirement for UAV Application

2.1. Operational Height
Flight operation is based on the mission. Legally it is below 400 ft, unless special permission is granted by Civil Aviation Authority of Malaysia (CAAM). For civilian used in mapping and remote sensing, this height depends on the camera specification and the resolution of the image.

2.2. Collision Avoidance
Once the UAV can fly beyond line-of-sight, there is a safety requirement to ensure it does not collide with another flying vehicle either manned or unmanned.

2.3. Signal Coverage
The flight mission sometimes require the airborne aircraft to fly in remote areas. Since the operation of UAV over cellular network depends highly on data-based network, coverage from 3G and beyond network is important as these network provides packet-based services [6]. This however might be a challenge in remote areas whereby deployment of 3G (and beyond 1) networks are absent. Figure 2 illustrates the coverage for 4G network in Peninsular Malaysia and East Malaysia. These data are obtained from users’ devices using an app and represent a maximum coverage of 50 meters for uplink and 200 meters for downlink. Based on the coverage map, Malaysia currently shows their readiness in providing 4G network for users [7, 8] although it might be limited to urban areas as illustrated in Figure 2 [9].

1 Third generation of mobile network and onwards.
Figure 2. Map showing 4G connection in Malaysia (information updated as of 23 March 2019) [9].

Figure 3 shows the regional performance of five largest operators in each category by OpenSignal measures. In OpenSignal’s regional analysis of Malaysia’s biggest cities, they examined seven core metrics for Malaysia’s five largest operators. Many of the results reflected the national results with Maxis winning 4G download speed and overall download speed awards in all five areas [8].

3. Challenges in Propagation Environment

3.1. Antenna Tilt Angle

The antenna at the base station (BS) is often tilt downwards for optimum coverage of terrestrial users [10]. Generally, as show in Figure 4 (a), a larger coverage area among terrestrial users can be achieved if the tilt angle of the antenna is small (shown by $\theta_1$). Conversely, increasing the downwards tilt angle of the antenna (shown by $\theta_2$) results in smaller coverage area (smaller cell size). The decision on the size of the cell depends on the demand of users wanting to connect
Based on Figure 4 (a), a larger downwards tilt of the antenna results in larger SNR at the cell edge (relative to the case where antenna’s tilt angle is smaller) at the expense of reduced coverage area hence smaller number of users are able to connect to the BS (assuming a uniform user distribution with fix density). On the other hand, a larger coverage area can be achieved with a smaller downwards tilt angle at the expense of reduced SNR at the cell edge.

Based on the standard 3GPP antenna radiation pattern in a 3 sector cell, the antenna gain is given by [11]:

\[ A(\theta) = -\min \left\{ 12 \left( \frac{\theta}{\theta_{3dB}} \right), A_m \right\} \]  

(1)

Where, \(-180 \leq \theta \leq 180\) is defined as the angle between the direction of interest and the bore sight of the antenna, \(\theta_{3dB}\) is the 3 dB beamwidth in degrees, and \(A_m\) is the maximum attenuation. This shows that the greater the angle between direction of interest and the bore sight of the antenna (direction with strongest radiation), the smaller is the gain. Hence not only the users at the edge are affected by the tilt angle, but users closer to the BS are also affected by different configuration of the antenna tilt angle. The general relation between tilt angle of the antenna and the received signal strength (represented by SNR) as well as the number of users connected to the BS is illustrated in Figure 4 (b). This figure shows that a larger downwards tilt angle of the antenna results in larger SNR being established but at the expense of reduced number of users obtaining coverage. This is because as the antenna is tilt further downwards, the radiation from the antenna is imposed onto a smaller area.

Consider the illustration of 3GPP antenna radiation pattern in Figure 5 [12], UAV network at high altitudes could potentially be connected to the BS through the side lobes of the antenna.
For a given horizontal distance with respect to the BS, the higher the altitude of the UAV, the smaller the antenna gain at the UAV (UAV2 has smaller received signal strength than UAV1 from the blue-shaded antenna radiation pattern). If the antenna is tilt further downwards, the UAV reception will be worsen and eventually disconnected from the BS if the received signal strength is below the specified threshold. For a given horizontal position, unlike the performance of the terrestrial users, the performance of aerial users degrades with increasing tilt angle.

The distribution of users also affects the decision on cell size and hence the tilt angle of the antenna. Smaller cell sizes such as Pico cellular network are often adopted to accommodate high number of users. In such dense cellular network, the UAV may receive connection not from its nearest BS but from a BS further away (UAV3 may receive reception from BS 2 in Figure 5).

The work in [4] investigated the performance of cellular based UAV network and considered practical interference mitigation techniques in their evaluation. However, their investigation is based on a typical rural area network. 4G networks in Malaysia illustrated in Figure 2 are mostly deployed in urban or sub urban areas. Since different environment would result in different types of cellular network deployment (which varies in cell sizes), the network performance might too differ. Therefore this opens for further investigation for cellular based UAV in urban or sub urban areas.

The investigation on UAV coverage performance particularly in important areas requiring UAV application in Malaysia would provide useful insight on the robustness of cellular based UAV network in the country.

### 3.2. Propagation Environment

Al-Hourani and Gomez [13] identified that several challenges exist in utilization of current cellular networks for UAV application, as they are purely designed to cater for terrestrial users. Flying UAV might face a large amount of neighboring interference as well as a different coverage behavior. Moreover, Qazi et al. [14] identified the shadowing loss and multi-path propagation as challenge for wireless signal propagation. When the receiver and transmitter have no clear line of sight, such as when wireless signal has to pass through obstacles (such as walls) it is referred to as shadowing loss. If the wireless signals sees intermittent reception of Line of Sight (LOS) signal and reflected versions of signals from other obstacles it is referred to as multipath propagation or fading.

### 3.3. Weather Conditions

Malaysia is known as a tropical region which involves two different peak seasons; a dry and wet season which are distinguished based on the average rainfall. The dry season refer to low rainfall rate with an average rainfall total of about 50 mm/hr [15, 16] whilst the wet season experience high rainfall rate. The normal characteristic of the rainfall in tropical region, including Malaysia is heavy with the average of 200 mm/hr and large raindrop sizes [17, 18]. Rain contributes to the attenuation in propagating radio wave through absorption and scattering process. To implement the 4G network with the UAV technology, several factor related to the effects of rain on the performance of 4G network need to be considered. This include rainfall rate under different operating frequency and effective path length. The other factor which needs to be taken into consideration is the type of polarisation which is horizontal or vertical polarization.

The 1st factor which is rain rate attribute to the attenuation of the propagated signal during rainy period. The propagation of signals from the source to the destination is effected by the rainfall in term of the signal can be absorbed, scattered and diffracted by raindrops. As the rain rate increases, raindrop size increases resulting in significant attenuation to the propagated signal. This lead to the communication link becomes disrupted and the probability of having connection lost is high and become more severe in tropical regions which experience high rainfall rates.
The 2nd factor is the frequency operation which affects the attenuation level due to rainfall. The higher frequency affects attenuation the most because the wavelengths become smaller and approach the size of the raindrop. When operate at frequency above the 10GHz, rain can give severe effect to attenuation. The width size of the raindrop in average is 1.67mm [19] for example, if high wavelength used such as 100 GHz, the raindrop size could be 3 mm, thus the attenuation of propagation signal increases due to the interchange of energy happened between the propagated wave and the raindrops.

The 3rd factor is effective path length which is the length between the source and destination that contribute to attenuation and disturbance of the propagation of waves during rainfall [19]. The effective path length is calculated based on the rainfall distribution as rainfall is not evenly distributed along the radio path length. Thus, the accurate rain attenuation is calculated as a function of the effective path length. The attenuation increases as the effective path length increases, more area is covered by rainfall between source and destination which increases the attenuation [20]. This is concluded that the total rain attenuation is directly proportional to the effective communication path length. Due to this, during heavy rainfall, only small coverage can be provided with short communication length. The path length between the source and destination should be taken into consideration when designing the 4G channel systems to reduce the effect of rain on the wave propagation.

The 4th factor is the type of polarization which affects the propagation of electromagnetic waves. The effect of the polarization has been studied by other research group such as Shresthal and Choi [21] which found that horizontal polarization resulted in 12.5 dB more compared to vertical polarization with the same frequency band of 18 GHz, the same path length, the same rain rate, and utilizing the same system. Thorvaldsen and Henne [22] also found that more attenuation is resulted in horizontal polarization with 26 GHz frequency band. The horizontal polarization provides more attenuation compared to the vertical polarization based on the higher rainfall rate and higher frequency bands. Due to these factors, the communication distance become short during rainfall and becomes severe in tropical regions that considered as heavy rainfall. As a result, the 4G coverage system will be very small compared to the cellular systems and need numerous small base stations for the respected area.

The path loss and signal coverage at certain location need to be determined first before setting up the wireless network for communication. Rain attenuation cause propagation loss, degrades the system performance and limits the usage of higher frequencies for communication system. The rain attenuation is calculated based on the amount of attenuation that occurs due to rain per unit distance. Specific rain attenuation is calculated based on the rain rate level and incident electromagnetic waves at specific location. For mathematical equation, rain attenuation, $A$ is calculated using the following equation:

$$A = aR^b$$  \hspace{1cm} (2)

Where $a$ and $b$ denote the regression factors that are subject to several factors such as operating frequency and radio wave polarization. Polarization type also gives effect to specific attenuation due to non-spherical nature of the raindrops, where normally vertical polarization attenuation level is less than horizontal waves. Value $a$ and $b$ can be accessed from ITU [10]. $R$ is the rain rate in mm/hr exceeded for 0.01% of an average year which can be obtained from the meteorological data.

Other factor need to be considered for rain attenuation is effective path length, $L_{eff}$. The effective path length can be calculated using the following equation:

$$L_{eff} = rL$$  \hspace{1cm} (3)

Where $L_{eff}$ refer to effective path length, $r$ refer to path reduction factor or distance factor introduced by ITU [11]. $L$ refers to actual path length between source and destination. The
model proposed by ITU provides rain attenuation estimation which is widely accepted around the world. However, the work performed in [18] demonstrate that such model does not fit well in tropical region. This section emphasizes that rainfall rate is directly proportional to rain rate, operating frequency, effective path length, and horizontal polarization which result in increasing path loss, limiting the coverage area and degrading the system performance such as reliability and stability. Thus, the 4G system require a lot of small base stations to cover the affected area.

4. Potential Application in Malaysia
Cellular based UAV would be useful for border security. The discovery of human trafficking camps and graves near Wang Kelian in May 2015 was a big blow to the national boarder security. The government has set up a royal commission of inquiry (RCI) in January 2019 to investigate the matter [23]. Malaysia shares land border with three neighbouring countries namely Thailand (646.5 km), Indonesia (2,019.5 km) and Brunei (481.3 km). UAV can be used to patrol these borderlines for the benefit of all related countries. In May 2007, the Malaysian government conveyed that UAV will be used to conduct surveillance on the country’s land and sea borders [24]. In United States, the U.S Customs and Border Protection (CBP) operated the Predator B drone since 2003 to relay information on suspected border crossings [25]. In September 2017 the organisation started using smaller hand-launched drones and in summer 2016 uses small drones with face recognition feature [26]. These examples show that cellular-based UAV plays an important role to enhance security and hence need to be explored.

Other than that, cellular based UAV can be utilized for agriculture activities. Malaysia is actively involved in agriculture activities. The country is the world’s number two in palm oil producer and exporter behind Indonesia. The Malaysian Palm Oil Council in its official website stated 4.49 million hectares of land in the country is under palm oil cultivation [27]. The country is also the worlds top 10 rubber producer to date. Although the focus on rubber is not as extensive as many years before there are still slightly over one million hectares of land cultivated with this crop [28]. With such land coverage, potential of UAV use can be very significant in many ways. Noting that both industries are still relying on hard labour, UAV can be utilised in various farm management applications.

Challenges may incur to implement cellular based UAV for agriculture as these agriculture areas are most likely located in rural areas. Based on Section II, 4G coverage in Malaysia is easily available in urban areas as compared to rural areas. With regards to the current deployment of 4G network in Malaysia presented in Section II, it would be desirable to focus the application of cellular based UAV in urban areas. Inspection of utilities such as power grid lines, railway track and river is important for maintenance purposes to avoid or detect any potential damage to these utilities. Some utilities however are not easily accessible directly for inspection hence the use of cellular based UAV would be useful. In 2017, it has been reported that Tenaga Nasional Berhad, TNB utilized drones for monitoring the power grid replacing the use of helicopter in the past which is costly [29]. Such inspection can be further enhanced if inspections using drones are not limited to a certain range between the drone and the controller which is possible with cellular based UAV.

5. Conclusions
Large range of UAV operation can be achieved with the aid of cellular network coverage whereby the information to control the UAV can be made remotely via the wireless network. The increased range of operation of the UAV has made it a desirable option for many applications given that the requirements for UAV operation are fulfilled. Some of the requirements are the need to operate the UAV over a minimum height, avoidance of collision with other flying vehicle and the presence of a reliable data-based coverage. In terms of the capability of providing sufficient network coverage, it has been identified that Malaysia has demonstrate its readiness
in providing 4G network although it may be limited to urban areas. In order to utilize cellular based UAV, some challenges must be acknowledge and addressed which includes compensating the network coverage of cellular network which are designed to optimized terrestrial users in the first place. Additionally, since Malaysia is a tropical region, challenges also arise in combating signal attenuation due to rainfall. Given that these challenges are carefully taken into account, the cellular based UAV would be a promising option to facilitate various sectors in Malaysia which include agriculture, security and utilities maintenance.

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