Effects of Rain Attenuation on Satellite Video Transmission

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***Abstract*—Heavy convective rain events are often experienced in tropical countries such as Singapore. The operation of high-speed satellite transmission in the Ka-band is therefore susceptible to attenuation. We present the setup of a high-speed link via the WINDS satellite using an ultra small aperture terminals (USAT). Video streaming is performed over the high-speed link so as to investigate the effects of rainfall on the signal strength of the link and the video quality. The video streaming is performed at two locations 40km apart in order to examine site diversity as a mitigation technique.**

I. INTRODUCTION

With the increasing demand for high speed satellite transmission, the operating frequency of satellite systems is moving from the current Ku band to the Ka, Q and V bands. With this shift to higher operating frequencies, the link condition becomes more susceptible to tropospheric attenuation [1] caused by rain or cloud cover. Poor link conditions can lead to signal outage.

Satellite service providers want to quantify the quality of service (QoS) of their transmissions [2]. In [3], the QoS of a satellite link was examined by analyzing the video and voice packet loss, jitter and transmission rate in the IP satellite environment. In [4], the link quality is studied through the simulation of a mobile satellite communication system. In [5], digital satellite TV transmissions are monitored and a new technique to provide adequate coverage to poor coverage areas is provided.

Since QoS is critical to satellite service providers, fade mitigation techniques [6] are often employed to combat the effects of attenuation. Two of the most commonly employed mitigation techniques are power control and site diversity [7].

In this paper, the quality of service in terms of packet loss and the video quality of experience (QoE) on a Ka-band satellite link are examined. The correlation between QoS, QoE, and rainfall rate is analyzed. The effectiveness of site diversity as a mitigation technique is also studied.

II. WEATHER EFFECTS

Satellite communication in the Ka-band often suffers from rain attenuation causing link outage. This is an especially critical issue around the equatorial region where tropical weather conditions are characterized by common convective rain events and extremely high rainfall rates.

A. Rain Attenuation

Rain along the transmission path is the major weather effect of concern for satellite communications operating at frequencies above 10 GHz. Raindrops absorb and scatter radio wave energy, which degrades the reliability and performance of the communication link. Rain effects are dependent on frequency, rain rate, drop size distribution and drop shape, which are determined by the type of rain [8].

Two common rain types are convective rain and stratiform rain. Convective rain arises from vertical atmospheric motions resulting in vertical transport and mixing. The convective flow occurs in a cell whose horizontal extent is usually several kilometers. The cell may be isolated or embedded in a thunderstorm region associated with a passing weather front. Because of the motion of the front and the sliding motion of the cell along the front, the high rain rate usually only lasts for several minutes. These rains are the most common sources of high rain rate events.

Stratiform rain typically shows a stratified horizontal extent of hundreds of kilometers, durations exceeding one hour, and low rain rates of less than 25 mm/hr. For communication applications, stratiform rain occurs for sufficiently long periods of time that a link margin may be required to exceed the resulting attenuation. Stratiform rain covers large geographic areas, and the spatial distribution of total rainfall is expected to be uniform. Likewise the rain rate averaged over several hours is expected to be rather similar for ground sites located up to tens of kilometers apart.

In most temperate or sub-tropical countries, stratiform rain events are the most common. Singapore however, due to its location just 1° north of the equator, experiences two main monsoon seasons. Rain events during these monsoon seasons are mainly convective rain events. The cumulative distribution function of the rainfall rate in Singapore for 2009 is shown in Figure 1. It can be seen that the rainfall rate exceeds 25 mm/hr for 0.3% of the time (about 26 hours in a year), which implies that most rain in Singapore falls as convective rain.

B. Site Diversity

Singapore is an island approximately 42 km long and 38 km wide. Since convective rain is very common, it is likely that it may be raining in the west of Singapore while there are clear skies in the east. Therefore, the use of site diversity as

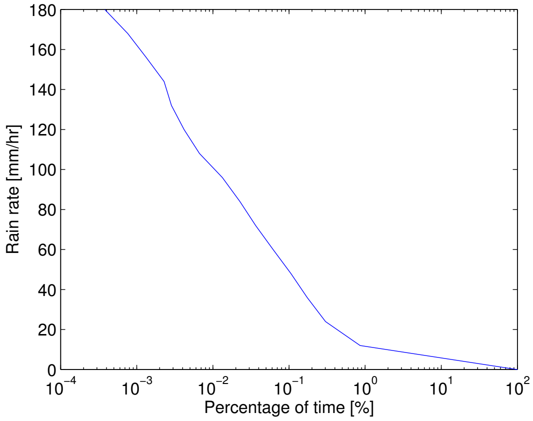

Fig. 1. Cumulative distribution function (CDF) of the rainfall rate in Singapore for 2009.

a mitigation technique for satellite communication links is a possibility and will be examined in this paper.

In order to solve the problem of excess attenuation due to the rain along satellite communication links, various technologies were proposed and investigated by researchers and system engineers. The mitigation techniques can be divided into two classes. The first type does not alter the basic signal format in the process of restoring the link, such as power control or site diversity. The second type requires the modification of the basic characteristics of the signal, such as frequency diversity, time diversity, bandwidth reduction, adaptive coding, and modulation [9].

Site diversity is one of the most popular methods to combat rain attenuation. A site diversity satellite system consists of two or more spatially separated ground stations, and hence, provides separate propagation paths to the signal. In practice, the two ground station diversity system is the most common. The plan view of the ground stations of a site diversity system is shown in Figure 2.

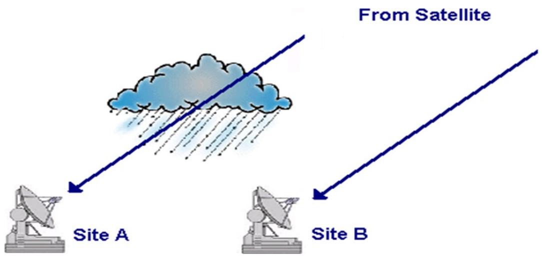

Fig. 2. Plan view of site diversity system.

The basic assumption of site diversity systems is that the rain attenuation will not significantly affect the two different propagation paths simultaneously as shown in Figure 2. Hence, by switching to the ground station with the higher received signal level at that instant in time, the effect of rain attenuation will be reduced significantly. This is the concept of selection combining diversity.

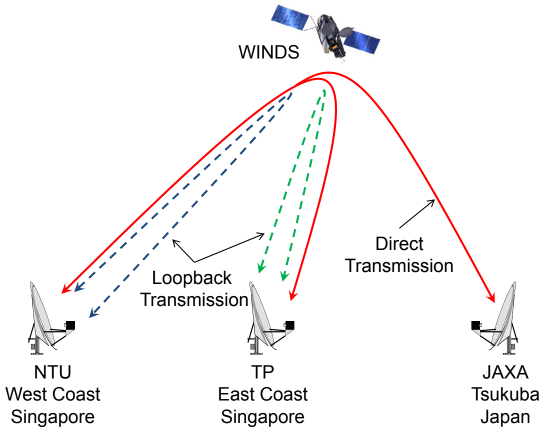

Fig. 3. Satellite connection via WINDS.

III. EXPERIMENTAL SETUP

A. *WINDS System*

The Wideband InterNetworking engineering test and Demonstration Satellite (WINDS) was jointly developed and launched by the Japan Aerospace eXploration Agency (JAXA) and the National Institute of Information and Communications Technology (NICT) in February 2008. The aim of this satellite is to provide high speed international Internet access to the Asia-Pacific region. As a result, countries with poor terrestrial communication infrastructure will be able to obtain high speed data communication services, enabling advanced applications such as disaster monitoring, telemedicine, distance learning.

The WINDS satellite is equipped with a Ka-band Active Phase Array Antenna (APAA) that can achieve up to 622 Mbps in data rate, which is one of the highest satellite data rates in the world. The APAA is able to direct its two beams to cover the whole of Japan and most of the Asia and Pacific regions. At the ground station, a very small aperture terminal (VSAT) or an ultra small aperture terminal (USAT) can be used to establish a high-speed Internet link. The size of these terminals makes them quite mobile and allows for high-speed Internet connectivity to be available anywhere.

B. *Satellite Configuration*

We use USATs at two different locations in Singapore. The two sites were chosen to provide good site diversity in order to mitigate rain attenuation and are about 40 km apart from each other. One USAT is located on the east coast of Singapore at Temasek Polytechnic (TP), and the other USAT is located on the west coast of Singapore at Nanyang Technological University (NTU). The experimental setup is shown in Figure 3.

From Figure 3, it can be seen that it is possible to establish a connection between JAXA in Tsukuba, Japan, as well as TP and NTU in Singapore. Besides these connections, it is also possible to establish a loopback connection where the information transmitted at a single site can be received back at the same site.

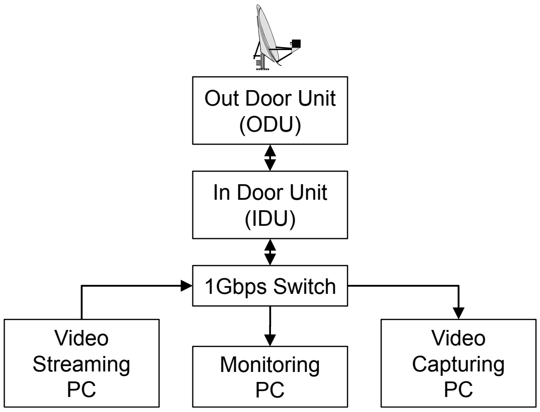

Fig. 4. Terminal configuration at each location.

The terminal configuration at each of the three locations is shown in Figure 4. The antenna is an offset dish antenna pointing at an elevation angle of 45° towards the east. The received signal is downconverted and amplifier by the outdoor unit (ODU). The downconverted signal is then processed and demodulated via the indoor unit (IDU). The transmit signal undergoes the same process but in the reverse direction.

Three computers are connected to the IDU via high-speed (1 Gbps) Ethernet switch. The monitoring PC monitors the IDU and ODU condition as well as the signal strength and packets passing through the terminal. Two other computers running Linux, one for video streaming and the other for video capturing, are connected to the IDU.

In the loopback configuration, the streaming PC transmits the video via the WINDS satellite and this video is received via the same USAT terminal at the capturing PC.

Using the USAT system, the uplink for the WINDS satellite operates at 28 GHz with 6 Mbps bandwidth, and the downlink operates at 18 GHz with 155 Mbps bandwidth. This is due to the small physical size of the USAT system. The USAT has an antenna that measures only 45 cm in diameter, which limits the gain and thus the maximum data rate of the uplink. The satellite system uses an ATM switching mode, where 288 time slots are located for transmission for the loopback link, which results in an effective usable data rate of 4.96 Mbps for video transmission in our experiment.

In order to study the QoS and QoE of the video transmission and its correlation with weather conditions, the rainfall rate at each location is recorded using a Davis weather station. The weather station makes use of a tipping bucket system with a resolution of 0.2 mm per tip. Measurements are recorded every minute.

To examine the effectiveness of site diversity and to correlate QoS and QoE with rainfall rate, a loopback transmission of a high definition video at each location is monitored for 48 hours once every month (this is when the APAA is pointing towards Singapore).

C. Video Streaming

We created our own test video for streaming. For this purpose, we chose the 10-second "old town" clip from the SVT High Definition Multi Format Test Set. The original clip is in uncompressed 1080p50 HD format and contains no audio. The clip shows a slow pan over the old town of Stockholm. This scene was selected because it is relatively easy to encode.

Before encoding, we converted the clip to the desired SD format through appropriate cropping and resizing. We used the MediaCoder software to compress the video using the H.264 (a.k.a. MPEG-4 AVC) codec. The original clip was played in a loop to create a 5-minute stream as input to the encoder. The SD video was compressed to 3.5 Mbps (roughly 70% of the available maximum data rate on the loopback link, see above). The video elementary stream was then encapsulated in an MPEG2 Transport Stream (TS) using the tsMuxeR program.

For further encapsulation into IP packets, we used a setup of 2 PCs connected via Ethernet switch. On PC1, we ran VLC to stream out the video as a multicast over RTP. On PC2, we ran Wireshark to capture the packets coming from PC1. This packet capture was then saved to a .pcap file. Using the bittwist program, the IP and MAC addresses in the capture file were modified as necessary for streaming via the satellite links. The resulting .pcap files were used as the base files for the actual experiment.

During the actual experiment, we use tcpreplay on the streaming PC to play back the .pcap base files at the sender side of the link. At the receiver side, the incoming packets are then captured on another PC using tcpdump and stored in a .pcap file for offline analysis (see below).

All the software programs mentioned above are freeware and available on the Internet.

D. Video Quality Measurement

Apart from studying the link quality in terms of physical layer or packet losses (what is generally referred to as QoS), we also investigate the impact of these link issues on an actual video transmission and the resulting video quality. The main cause for video impairments in the setup described above will be transmission problems, i.e. bit errors on the physical layer leading to packet losses or excessive jitter. While a lot of effort in video quality measurement has been devoted to evaluating compression artifacts from decoded "base-band" video [10], this is not necessarily the best approach for this purpose.

Because losses directly affect the encoded bitstream, metrics based on parameters that can be extracted from the transport stream and the bitstream with no or little decoding are more suitable here. This has the added advantage of lower processing requirements compared to metrics looking at the fully decoded video.

In this paper, we rely on the V-Factor metric [11], a video quality measurement tool that uses the received packets as input directly. It combines packet loss modeling with information obtained from the video stream. The V-Factor algorithm is designed mainly for MPEG-2 and H.264 video streaming over IP networks.

The V-Factor metric is based on deep packet inspection of the video stream (see Figure 5). It analyzes the bitstream in real time to collect static parameters such as picture size and frame rate as well as dynamic parameters such as the variation of quantization steps or motion activity. Video quality measurement is then based on the following:

- The impact of network impairments such as jitter, delay and packet loss on the video, including spatial and temporal loss propagation.
- The impact of content characteristics, the compression mechanism and bandwidth constraints.

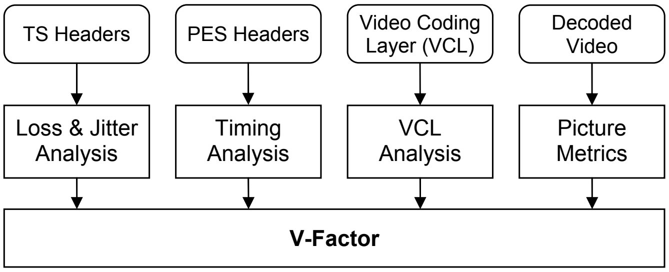

Fig. 5. V-Factor inspects different sections of the video stream, including transport stream (TS) headers, packetized elementary stream (PES) headers, video coding layer (VCL), and the partially decoded video signal [11].

The underlying model used for the objective measurement of video impairments is based on a paper by Verscheure et al. [12], who proposed models for the impact of packet loss rate, MPEG-2 quantizer scale and data rate on quality using the moving picture quality metric (MPQM). V-Factor uses generalized models for the H.264 codec format and additionally takes into account the complexity of the video content. Hidden Markov models are used to estimate packet loss probabilities (single loss, bursty loss) and the impact of network impairments on different frame types (I, P, B) etc. Consequently, the V-Factor metric also provides detailed loss and jitter information about the video transmission.

Finally, the different measurements are pooled together into an overall video quality rating on a scale from 1 (bad) to 5 (excellent), based on the Mean Opinion Score (MOS) obtained from subjective experiments.

IV. MEASUREMENT RESULTS

A loopback video transmission was established at both NTU and TP in order to study the effects of site diversity. A 3.5 Mbps video was transmitted from the video streaming computer at NTU and then captured at the video capturing computer at the same location via the WINDS satellite. The same experiment was performed at TP simultaneously. At both locations, the rainfall rate during the experiment was also recorded. The video quality measurements of the packet captures were performed offline after the experiment.

We present a first analysis of the data collected during the experiment conducted on December 29-30, 2009. During this experiment, two rain events were recorded at NTU, one stratiform and one convective rain event. The stratiform rain event occurs at around 30.5 hours into the experiment; it lasts for about 15 minutes and has a peak rainfall rate of 12 mm/hr. The convective rain event occurs at around 32.4 hours into the experiment; it lasts for only 3-4 minutes and has a peak rainfall rate of 48 mm/hr. The rain data of interest around the rain events observed at NTU is shown in Figure 6(a).

For both rain events there is a drop in signal strength. As shown in Figure 6(c), the stratiform rain event resulted in a signal strength drop of up to 8 dB, whereas the convective rain event resulted in a signal strength drop of up to 17 dB.

Both rain events lead to severe packet loss on the link, which in turn has a drastic effect on the video quality. When the signal strength decreases to its first minimum of -24.3 dBm, 30.5 hours into the experiment, the packet loss reaches 100% and the connection is lost for about 4 minutes. When the signal strength decreases to its second minimum value of -33.2dBm, 32.4 hours into the experiment, the connection is again lost for about 10 minutes.

In conclusion, the data show a very good correlation between rainfall rate, signal strength, IP packet losses, and the V-Factor score.

The data also show that the link is perfect most of the time when no rainfall is recorded, i.e. no packets are lost, and video quality is close to the maximum value of 5. However, even during those periods of no rainfall, sporadic packet losses occur from time to time, and video quality is affected accordingly. This might be due to the various effects such as cloud cover, scintillation or depolarization.

No rainfall was recorded at the TP site during the entire period of that experiment. As a result, the video link at TP was good and exhibited no losses, illustrating the potential for effective site diversity in our setup.

V. CONCLUSIONS

We presented an experiment for video transmission over satellite, using a high-speed link between the WINDS satellite and two ultra small aperture terminals (USAT). This experiment was conducted in order to study the effects of weather conditions on the high-speed satellite link, in particular the different types of rain encountered within the tropical region. Monitoring the rainfall rate, packet loss rate, and overall video quality, we established a strong correlation between these three parameters. Future work will focus on a significant expansion of the dataset, which will allow a closer look at other network and video quality parameters, as well as the benefits of site diversity in our setup.

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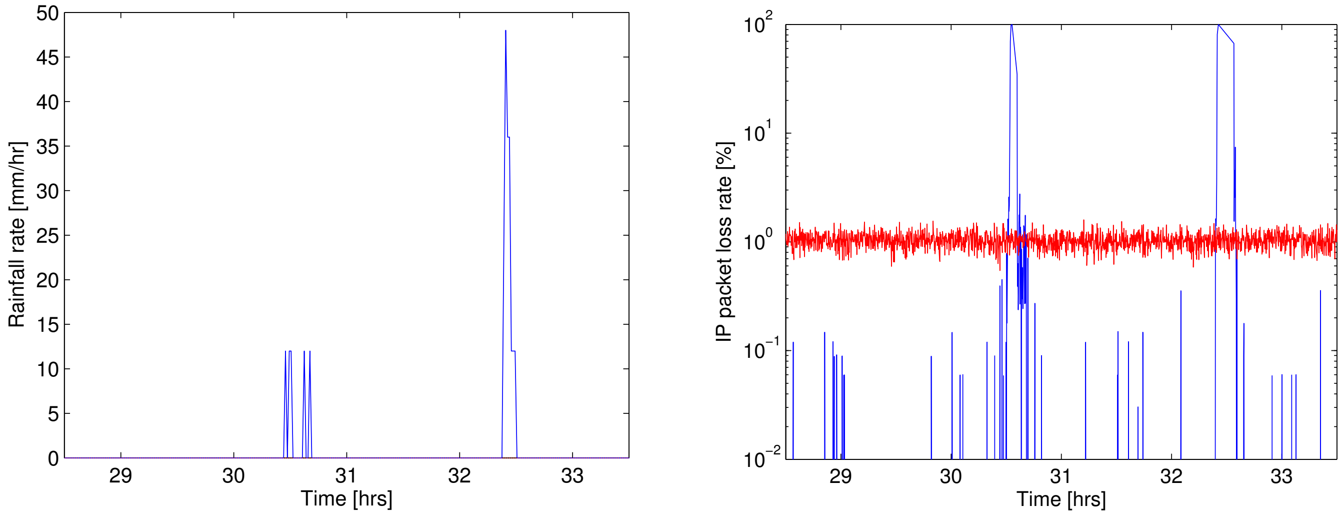
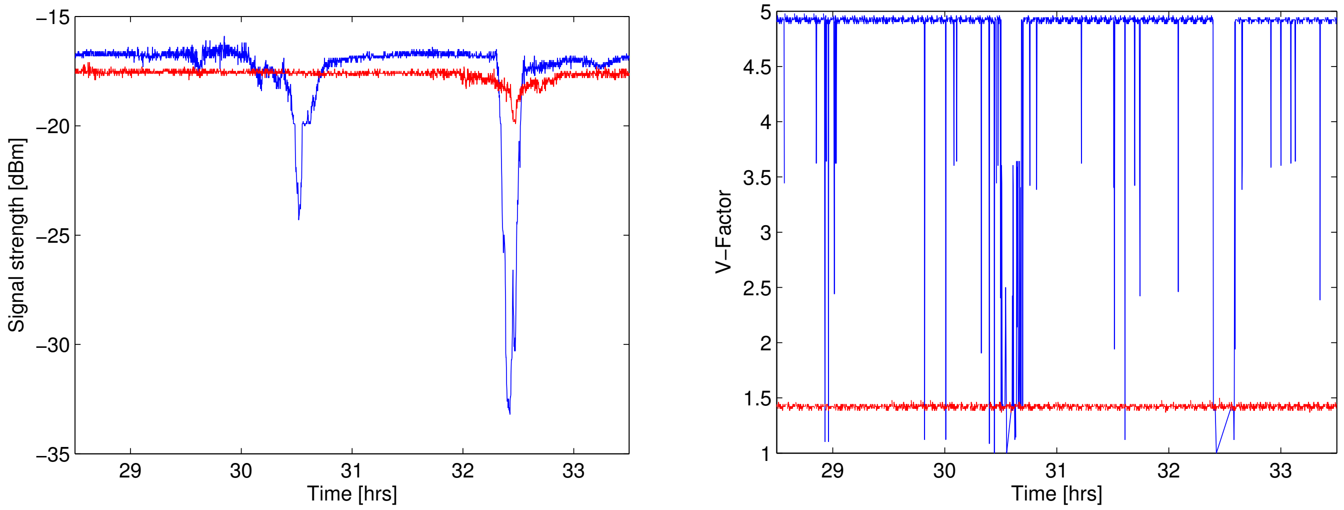


(a) Rainfall rate (b) IP packet loss rate



(c) Signal strength (d) V-Factor Score

Fig. 6. Rainfall rate (a), signal strength (b), IP packet loss rate (c), and V-Factor score (d) recorded at NTU site during one experiment.

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