Radio Wave Propagation Studies in Singapore

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Abstract

The radio wave propagation studies in Singapore carried out in recent 10 years are reviewed in this paper. Three research areas will be covered, namely, rainfall attenuation of microwaves propagating along both sight-of-line and satellite link paths, radio wave propagation in tropical forest environment, and radio wave propagation in urban environment. Brief description of the state-of-art R & D work in these areas will be given.

I Introduction

It is well-known that knowledge of radio wave characteristics in different electromagnetic environments is very essential for the design of telecommunication systems, for instance, planning of mobile phone station distribution. With the increasing demand of telecommunications especially mobile communications, radio wave propagation becomes important in the radio systems in global communication network system. In Singapore, the radio wave propagation studies started in 1960s when HF radio wave propagation through, and scattered by, ionosphere were investigated. After that, the research work on radio wave propagation stopped for more than 20 years until the telecommunication system requires the information of characteristics of radio waves in various environments.

After a long break, studies on radio wave propagation were put on schedule in 1988 when the Singapore Telecommunication Pte Ltd (SingTel) sponsored a research into the specific microwave rainfall attenuation at 21.225 GHz. Also, a company in UK provided transmitter and receiver systems for the real-time data collection. Attached to the receiving system, a computer equipped with software is set up to extract automatically the rainfall parameters over a sight-of-line link of 1.1 km [1–16]. In about 1992, two satellite-to-ground links were set up to investigate experimentally the rainfall attenuation as well as the effects of troposphere. At the same time, various theoretical and modeling works were carried out to compute total (or extinction) cross section of raindrops of spherical, oblate-spheroidal and Pruppacher-and-Pitter shapes. Effects of the rain drop shapes were thus investigated, sponsored by Ministry of Education, Singapore.

Since 1994, investigations on radio wave characteristics in tropical rain forest environments started, sponsored by Defence Science Organization (DSO) National Laboratories. Both theory (of ray tracing, UTD approach, and full-wave method) and experiments were looked into. Theoretically, a forest model of four regions consisting of a semi-infinite free-space, a single-layered canopy, a single-layered trunk, and a semi-infinite ground plane was proposed and two cases are considered, namely, isotropic canopy and trunk media and anisotropic canopy and trunk media. Various wave propagation mechanisms were realized, including the direct wave, a dominant and two fast-decayed lateral waves.

Since about 1995, radio wave propagation in urban environment for indoor communications was studied, sponsored by Ministry of Education, SingTel, and another mobile communication company, Mobile One (M1). Both theoretical (using UTD and Monte Carlo) and experimental studies were conducted. A fairly good prediction model for a few selected areas including the downtown city was obtained.

Subsequently, we will briefly review the studies of radio wave propagation in the aforementioned three subareas.

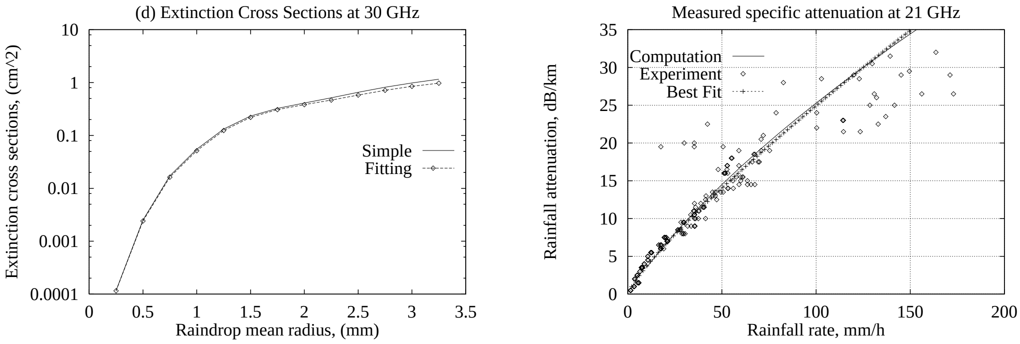
II Microwave Rainfall Attenuation

Rain attenuation of microwave signal is a problem faced by telecommunication service providers and air- and space-borne microwave imaging sensors in the tropics due to the frequent heavy rainfall. Without proper link budgeting a communication link will be subjected to frequent service interruptions, and a microwave imaging sensor could be put out of commission when it is needed most. Although studies have been conducted in Europe and USA dating back to the 1940s, it is found that the results are not suitable for use in tropical climates. It was revealed in a trial conducted in 1988 at 21.225 GHz that local rain attenuation of microwave far exceeded both the CC ITT and the supplier's recommendation. Two more communication links at 15 GHz and 38 GHz were subsequently added in 1993. More than one year each of data have since been collected at these three frequencies and in both vertical and horizontal polarizations. As the microwave rainfall attenuation is directly related to both the extinction cross section and the raindrop size sections, the following two subsections will describe what has been obtained in Singapore.

A Extinction Cross Sections

A typical and well-accepted model for simulating the realistic varying raindrop shapes was developed earlier by Pruppacher and Pitter who solved a pressure balance equation at the surface of falling raindrops by numerical techniques and determined the shapes of raindrops of various sizes theoretically. Hence, the model well-describing the raindrop shapes is referred to as the *P*ruppacher-and-*P*itter (P-P) model. The raindrop shapes as a sphere when the size is small, as an oblate spheroid when the size is medium, and as a Hamburger when the size is large. However, it is almost impossible, as indicated by Oguchi, to solve this nonlinear equation analytically and to yield the raindrop shapes very easily. To simplify the computation, a cosine series was introduced to replace the Pruppacher and Pitter's nonlinear equation. The computation becomes straightforward, and to look at the characteristics of the raindrop distortion and its influence on the rain attenuation is still very difficult. On the one hand, to determine the coefficients of the expanded EM fields is not so easy because the series consists of nine terms. On the other hand, to calculate the attenuation caused by such raindrops is not convenient because the nine parameters in that cosine-series expression vary with the effective drop radius a_0. To simplify the calculation of rain attenuation, a new model of the varying raindrop shapes, which uses different functional expression to describe the upper-half and the lower-half of the raindrop scatterer, has recently been developed by Li et al. [4]. It shows that the new model is acceptable not only because it is evidently more realistic than the earlier models of spheroids and ellipsoids but also because the model is simpler than the cosine series model so that the contribution of the raindrops' non-axisymmetry to the microwave attenuation can be obtained analytically. Then, two different approaches were proposed, one is the perturbation approach [5] while the other is the simplified equivolumetric approach [14].

We have numerically calculated the specific rainfall attenuation and depicted it as an example at 21.225 GHz in Fig. 1 where "*Computation*" denotes the predicted results numerically calculated in this paper, "*Experiment*" represents the measured data experimentally collected in Singapore, and "*Best fit*" stands for the best fit curve of the experimental data using the least squares fitting. From Fig. 1, a reasonably good agreement between total cross sections obtained at 30 GHz using two different methods between the predicted specific rainfall attenuation and the measured data (or the best fit curve) is obtained at 21.225 GHz.



(a) TCS's (in cm^2) of spheroidal raindrops numerically computed at a frequency of 30 GHz and at temperature of 20^{o}C

(b) Comparison of specific rainfall attenuation of horizontally polarized microwaves at 21.225 GHz

Figure 1: Total cross section of raindrops and specific rainfall attenuation.

B Raindrop Size Distribution

Based on the collected data [1–3, 13, 14, 16], a negative exponent distribution for the local rain drop size distribution was derived using the exact Mie Theory and total extinction cross section computation of spheroidal rain droplets. Compared with the new model, the Laws and Parsons model and the Marshall and Palmer model grossly estimated the number of large droplets (for up to an order of magnitude of more) while overestimated the number of small droplets. As a results, CC ITT recommendation could be 10 DB (per km) or more lower than the actual path measured attenuation. The new model would be useful for the computation of rain attenuation in the frequency range of 10 - 40 GHz, rain rates between 0 to 200 Mme/hrs and arbitrarily-polarized microwave links.

From experimental data collected at 15, 21.225, and 38 GHz, the following models of attenuation A (in dB/km) against rain rate R (Mme/hrs) are developed for both horizontal and vertical polarizations:

$$A_{horizontal} = \begin{cases} 0.5973R^{0.6934} & \text{at 15 GHz} \\ 0.4809R^{0.8266} & \text{at 21.225 GHz} \\ 8737R^{0.8193} & \text{at 38 GHz} \end{cases} ; \quad A_{vertical} = \begin{cases} 0.6336R^{0.6206} & \text{at 15 GHz} \\ 0.6064R^{0.7486} & \text{at 21.225 GHz} \\ 6423R^{0.8365} & \text{at 38 GHz} \end{cases} . \quad (1)$$

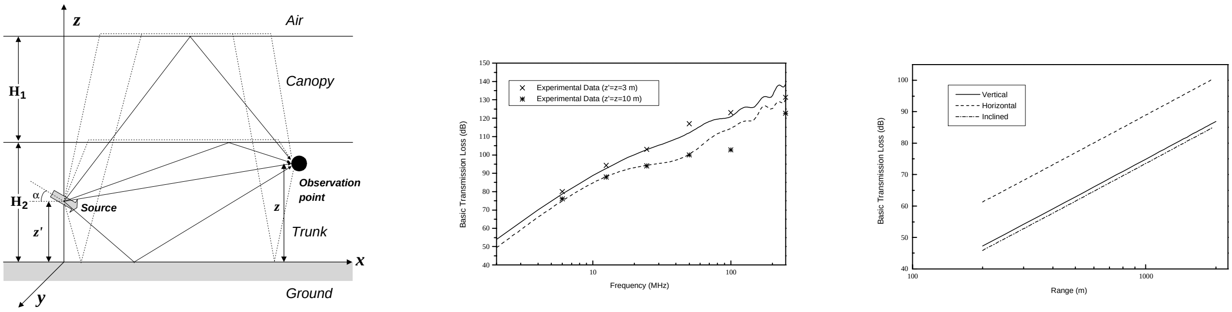
Similarly, a raindrop size distribution model $N(D)$ is obtained and given below:

$$N(D) = N_0 \exp\left[-\alpha R^{-\beta} D\right] = 0.0318 \exp\left[-2.816 R^{-0.2} D\right] \quad \text{in cm}^{-4}, \tag{2}$$

where the raindrop diameter D is in Mme. These models are generated from the 1.1 km link. The results for the satellite link are not completed yet and will hence not be reported here.

III Radio Wave Propagation in Tropical Forest Environment

The anisotropic stratified model for radio wave propagation through forests is shown in Fig. 2 [17–22]. As can be seen in this figure, the forest is made up of electrically anisotropic canopy and trunk slabs, positioned between electrically isotropic air and ground. The heights of the canopy and trunk layers, measured along the z-direction are H_1 and H_2, respectively, while the heights of the air and ground regions are infinite. Numerical results for the radio losses are computed in this paper and shown in Fig. 2, using parameters suggested by Cavalcante et al. in the frequency range of 2 to 250 MHz. Under these conditions, it is adequate to represent the forest by homogeneous and isotropic media, thus $\epsilon_t = \epsilon_z$. As observed from Fig. 2(a), our theoretical results are in good agreement with the experimental data given by Dence and Tamir. It is noted that the lateral wave along the upper-side of the air-canopy interface is the dominant wave at these frequencies. In Fig. 2(b), the radio losses calculated using the lateral-wave contribution to the field are shown as functions of the horizontal distance between transmitting and receiving dipoles with vertical, horizontal and inclined polarizations. The optimum inclination of the transmitting dipole is found to be 79.33° for this case.



(a) Stratified forest model and ray tracing geometry of the direct and singly-reflected waves, and lateral waves (— Direct and Reflected Waves, - - -Lateral Waves)

(b) As a function of frequency for transmitting and receiving dipoles separated by 1 km (— $z' = z = 3$ m, - - - $z' = z = 10$ m)

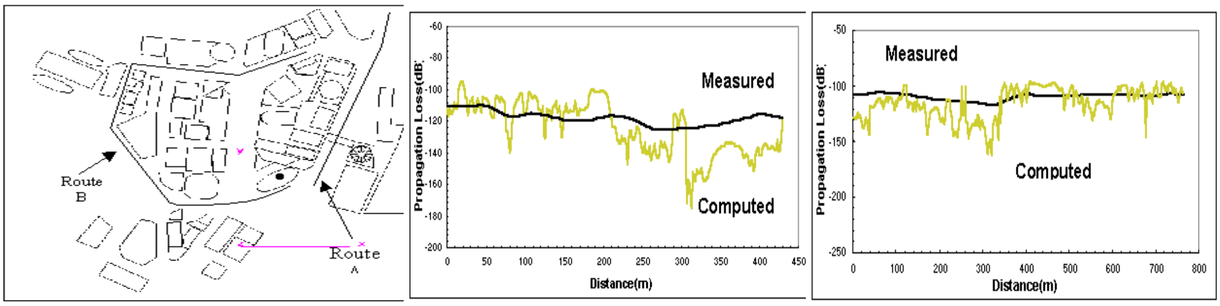
(c) As a function of distance at 5 MHz ($z' = z = 3$ m)

Figure 2: Radio loss for transmitting and receiving dipoles located within an average forest. Also shown are the experimental data by Dence and Tamir [1969]. Parameters used: $\epsilon_2 = \epsilon_{2t} = \epsilon_{2z} = 1.12$, $\sigma_2 = 0.12$ *mS/m,* $\epsilon_3 = \epsilon_{3t} = \epsilon_{3z} = 1.03$, $\sigma_3 = 0.03$ *mS/m,* $\epsilon_4 = 20$, $\sigma_4 = 10$ *mS/m,* $H_1 = 9$ *m,* $H_2 = 1$ *m.*

IV Radio Wave Propagation in Urban Environment

A study was performed to consider multipath propagation in urban areas without line-of-sight (LOS) propagation often referred to out-of-sight (OOS) propagation [23]. Our analysis used the Near Zone - Basic Scattering Code from the Ohio State University. This program uses the Uniform Theory of Diffraction (UTD) with ray tracing techniques to predict the scattered fields. Several scattering terms are used including, single and double reflected fields, singly diffracted fields, reflected-diffracted and the diffracted-reflected fields. In addition, scattering from both flat and curved surfaces is considered. The building structures were mostly simulated using rectangular blocks. The building coordinates were estimated using maps.

The urban area selected for the study is Raffles Place, the central business district of Singapore. A local wireless provider provided CW drive data at 937 MHz. Specifically, two routes were used in the study, as indicated in Fig. 3. The constitutive parameters for the model are and 7 S/m for the building walls and and 0.001 S/m for the ground. The transmitter location is on top of the building indicated by the dot in Figure 1. The measured vs. predicted propagation loss are shown in Fig. 3. In route A, the drive path is located to the right of the transmitter location. There is a dip in the received field located at about 75 meters due to a building overpass. This was correctly predicted using the UTD analysis. Further along the route, the measured vs. predicted fields diverge. This was later found to due a specular reflection from a side of a building not included in the model. In route B, the UTD model predicted the general characteristics of the drive test data. Of particular interest, is the measured dip in the received field located at about 300m. This was due to the diffraction effects from the roof of a building adjacent to the transmitter and a specular reflection from another building.



(a) (b) (c)

Figure 3: Measurement of field distribution in urban area in Singapore: (a) UTD Model of Raffles Place area of Singapore, (b) Measured vs. Predicted Propagation loss for Route A, and (c) Measured vs. Predicted Propagation loss for Route B

V Conclusion

In this paper, the radio wave propagation studies in Singapore in the recent 10 years are reviewed. Three basic areas are covered, rainfall attenuation of microwaves propagating along both sight-of-line and satellite link paths, radio wave propagation in tropical forest environment, and radio wave propagation in urban environment.

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