

Effective statistical G/T (ESGuT): A parameter describing the performance for non-GEO satellite systems

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A new parameter called the effective statistical G/T (ESGuT) is introduced. This parameter describes the downlink performance of a non-GEO satellite personal communication network (SPCN) taking into account the performance of the antenna on the mobile, the average effect of the environment, the handling of the handsets by the user and the satellite orbit statistics.

Introduction: The figure of merit (G/T) is one of the major contributors to the calculation of system performance for an Earth-space link. It includes the performance of the antenna used on the mobile and the noise contribution from the environment and the receiver to that antenna [1]. In this Letter, the effective statistical G/T (ESGuT) is introduced as the most useful measure of handheld terminal performance in a satellite PCN system operating using non-geostationary satellite constellations. A calculation procedure for the ESGuT is presented and used to compare the impact of different antenna pattern shapes, satellite constellations, environments and the influence of the orientation of the handheld.

Down-link budget: The downlink budget formula can be written as a function of the polar co-ordinates θ (elevation) and ϕ (azimuth):

$$\frac{C}{N}(\theta, \phi) = EIRP(\theta, \phi) + \frac{G}{T}(\theta, \phi) + 10\log(B) - L_{total}(\theta, \phi) - K + M(\theta, \phi) \quad (1)$$

where $C/N(\theta, \phi)$ is the ratio of signal power to noise power, $EIRP(\theta, \phi)$ the effective isotropic radiated power from the satellite antenna and $G/T(\theta, \phi)$ the figure of merit of the handheld antenna.

$$L_{total}(\theta, \phi) = FSL(\theta, \phi) + L_{atm}(\theta, \phi) + L_{interference}(\theta, \phi) + L_{polar}(\theta, \phi) \quad \text{total losses} \quad (2)$$

where $FSL(\theta, \phi)$ represents the free space losses, B is the bandwidth, K is Boltzmann's constant and $M(\theta, \phi)$ is the link margin.

In the case of an isoflux satellite antenna pattern the factor $[EIRP - FSL](\theta, \phi)$ is constant. The relative position and the distance between transmitter and receiver are changing, but the satellite antenna pattern compensates for the extra free space loss. The quality of communication is also affected by factors such as the losses (L) and the noise temperature (T), which in turn depend on the variation of the handheld antenna radiation pattern $G(\theta, \phi)$ and the profile of the noise sources [2, 3] with respect to the azimuth and elevation angles θ and ϕ .

Communication between the orbiting satellite and the mobile can be established in all these locations (defined by the angles θ, ϕ) where the link margin $M(\theta, \phi)$ is adequate. Hence, there is a need to know the values of $G/T(\theta, \phi)$ and $L_{TOTAL}(\theta, \phi)$ for every (θ, ϕ) in every antenna pattern, environment profile, satellite system and user handling combination.

The losses in the link can be found with the use of existing propagation models [4]. The rest of the factors involved (antenna pattern, environmental profile, satellite system and user handling of the terminal) are included in the newly defined ESGuT parameter.

Calculation of G/T : The quantity G/T can be expressed in decibels as follows:

$$\frac{G}{T}(\theta, \phi)_{dB} = G(\theta, \phi)_{dB} - 10\log(T_A) \quad (3)$$

and

$$T_A = \frac{\int_{\varphi} \int_{\theta} P_n(\theta, \varphi) T_s(\theta, \varphi) d\Omega}{\Omega_A} = \frac{1}{\Omega_A} \int_0^{2\pi} \int_0^{\pi} \frac{P(\theta, \phi)}{P_{max}} T_s(\theta, \phi) \sin \theta d\theta d\varphi \quad (4)$$

where $G(\theta, \phi)$ is the antenna gain power pattern in dBi, $E(\theta, \phi)$ the

antenna power gain ($= 10^{G(\theta, \phi)/10}$), $P_n(\theta, \phi)$ the normalised antenna power pattern and P_{MAX} is the maximum power.

$$\Omega_A = \int_0^{2\pi} \int_0^{\pi} P_n(\theta, \phi) d\Omega \quad (5)$$

is the solid angle of the pattern, $T_s(\theta, \phi)$ the directional temperature of the environment and T_A is the noise temperature received by the antenna.

The building surfaces and the ground are assumed to be at (273 K + average local temperature) [1, 2]. The sky, the sun and the background contribute different amounts of noise at lower temperatures [2, 3].

The thermal noise from the building is calculated from eqn. 4 using the edges of the building profiles as integration limits. These profiles can be produced by using real pictures or by building typical geometrical models representative of different types of environment with the method described in [5].

User handling effect: In the case of SPCN handhelds, the quadrifilar helical antenna (QHA) seems to be the most appropriate antenna solution since it has a hemispherical or cardioid pattern which is symmetrical around the z-axis with circular polarisation [6].

In the calculation of $G/T(\theta, \phi)$, the pattern can be assumed to be in the upright position. Hence, only an elevation need be used in the integration of eqn. 4. This simplified method cannot be used when the pattern is tilted (the user is tilting the mobile terminal) because it is no longer symmetrical around the vertical z-axis. One solution would be to use all the elevation cuts of the tilted pattern (with 1° spacing in the azimuth $-\phi$) to calculate the $G/T(\theta, \phi)$. This method is not only difficult and time consuming but is also highly specific to the orientation of the user with respect to the local environment. To make global predictions, it is better to adopt an azimuth-averaged pattern, equivalent to assuming that the user's orientation is uniformly distributed.

The discrete averaged pattern is then found for 360×180 azimuth \times elevation points as

$$G'(\theta_m) = \frac{1}{180} \sum_{j=1}^{180} \left[\frac{1}{k_j} \sum_{i=1}^{k_j} G(\theta_i, \phi_j) \right] \quad (6)$$

where k_j is the number of θ_i for which for $|\theta_i - \theta_m| < 0.5^\circ$, each azimuth ϕ_j ($\phi_j = 0^\circ, 2^\circ, 4^\circ, \dots, 360^\circ$), $m = 0, 1, \dots, 359$ the elevation points of the 3D pattern, and $j = 1, 2, \dots, 90$ the azimuth points of the 3D pattern. The $G/T(\theta, \phi)$ is then calculated by eqn. 4 using the pattern from eqn. 6.

Definition of ESGuT: The values of the G/T pattern calculated in the preceding Sections could be used directly within a downlink link budget to predict the link performance for each satellite elevation angle. A better global approach for system design and analysis is to use the statistics of the satellite elevation to calculate the effective statistical G/T (ESGuT) as defined in eqn. 7:

$$ESGuT = \int_0^{90^\circ} GT(\theta) \cdot SSS(\theta) d\theta \quad (7)$$

where $GT(\theta)$ is the calculated G/T pattern. $SSS(\theta)$ are the satellite system statistics (% time in elevation angle and latitude) assuming a uniform distribution of satellite azimuth with respect to the environment. The same approach can be used to calculate the ESGuT for the first (highest) and the second (lower) satellite.

Table 1: Thermal noise calculated for QHA and isotropic pattern

	QHA upright	QHA 30° tilt	Isotropic
Light urban	118K	112K	180.6K

Results: In Fig. 1a a typical QHA pattern [6] is shown in its upright position and in Fig. 1b when it is averaged after a 30° tilt using eqn. 6. In Fig. 2 the building profile process is presented. A fish-eye lens picture is transformed to an azimuth against elevation representation and then the building profile is extracted to be used as integration

limits in eqn. 4. In Table 1, the noise temperature calculated for the previous patterns and an isotropic case are presented. In the isotropic case more noise is received because the ground and the buildings are included in a main lobe, whereas the tilted pattern receives less noise than the upright one because the elevation of the main lobes is higher and fewer buildings and less ground are included.

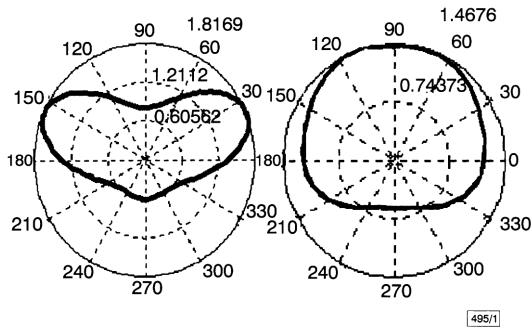


Fig. 1 Typical QHA patterns

a Upright position
b 30° tilted and averaged

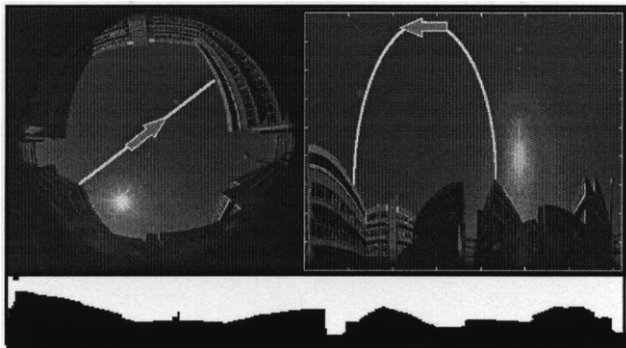


Fig. 2 Building profile extraction process (light urban environment)

Finally, in Fig. 3 the calculated ESGuT for the aforementioned QHA and light urban environment is presented. The statistics of the ICO system are used [1]. When the pattern is tilted the second satellite has a constant average G/T with latitude which is almost 1 dB/K better than that for the first satellite. When the antenna is tilted by 30° the average G/T for both satellites is the same and almost 2 dB/K lower than that in the upright position.

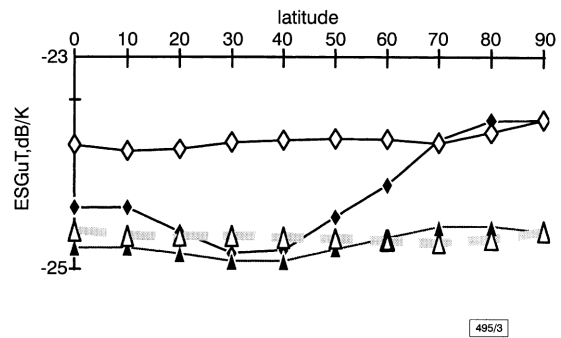


Fig. 3 ESGuT parameter calculated for aforementioned antenna and environment and ICO satellite system

◆ 0°, 1st satellite
◇ 0°, 2nd satellite
▲ 30°, 1st satellite
△ 30°, 2nd satellite

Conclusions: A new parameter ESGuT was presented. It accounts for all relevant parameters, including the satellite system, the user, the propagation environment and the antenna itself. It represents the average effect of these parameters and characterises the overall system performance without any specific directional dependencies.

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