Narrowband IoT service provision to 5G User Equipment via a satellite component

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***Abstract*—**

Today an estimated 15 billion of connected objects communicate with each other's. These connected objects that compose the Internet of Things (IoT) are expected to extend to 50 or 80 billion worldwide by 2020. Bringing wide-area connectivity for the IoT using satellite technology is therefore an attractive solution to complement terrestrial networks, allowing densification and coverage extension in remote areas. This paper deals with seamless integration of satellites and high altitude platforms (HAPS) into 5G networks. It describes the necessary modifications to operate on 5G systems in order to take satellite and HAPS specifics into account. Link budget calculations and system dimensioning, including channel modeling, are provided to determine the required satellite and HAPS performance as well as to estimate the number of served users per km².

Keywords*—*5G Services; satellite, 5G CHAMPION.

I. INTRODUCTION

This paper describes an innovative approach to extend seamlessly the 5G service coverage using satellite or HAPS based component integrated in the 5G architecture.

It first describes the service concept. It then describes the network architecture and identifies the radio protocol configuration and enablers for 5G user equipment devices to access the service activated upon software configuration. Last it analyses the service and network performance via satellite and HAPS.

II. 5G SERVICE VIA SATELLITE OR HAPS

A. Service concept

Enabling standard user equipment to access 5G via satellite in addition to cellular network, as shown Figure *1*, will open new market and usage opportunities.

Users of the consumer market may travel to areas without or simply out of order cellular nework infrastructure

Machine Type Communications and personal emergency communications that can address critical applications especially in the area of security, transportation, automotive and energy/water utilities sectors are targeted.

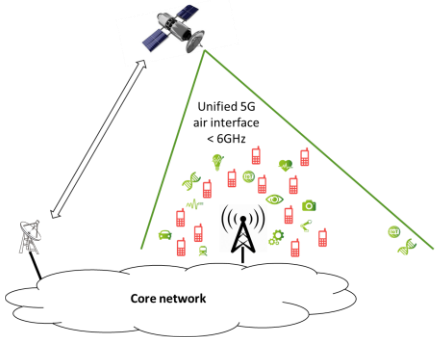

Figure 1 : Satellite MTC unified air interface concept.

B. System description and frequency bands

To provide the targeted service to small terminals different satellite systems or a HAPS can be considered

- High Altitude Platforms (HAPS) : stratospheric balloons at 20 km altitude
- Low Earth Orbiting (LEO) satellites with two variants
  - Altitude 800 km
  - Altitude 1500 km
- Medium Earth Orbit (MEO) satellite.at 10000 km altitude
- Geostationary satellite at 35585 km altitude

Typical values for the mean area covered by a single beam, the number of beams per satellite (or HAPS) and the number of satellites are given in Table *1* for each configuration. For interference management issues, all beams cannot use the full frequency bandwidth. Table *1* also specifies typical frequency reuse factors for each configuration. For instance, a frequency reuse factor of 1/4 means that half of the total bandwidth is used by each beam on a given polar.

Table 1: Area covered by a single satellite or HAPS

	Area covered per beam (km²)	Number of beams	Number of satellites/HAPS	Frequency reuse factor
HAPS	5000	1	NA	1
LEO	25000	50	100	$^1/_6$
MEO	50000	20	15	$^1/_4$
GEO	100000	300	1	$^1/_4$

The frequency bands are given in Table *2* for satellite systems and in Table *3* for HAPS.

Table 2: Service Links frequency Bands for satellites (GEO, MEO, LEO)

	Uplink (UE to Satellite)	Downlink (Satellite to UE)
Spectrum	1980 – 2010 MHz	2070 – 2100 MHz

Table 3: Service Links frequency Bands for HAPS

	Uplink (UE to HAPS)	Downlink (HAPS to UE)
Spectrum	1885-1980 MHz	2010-2025 MHz 2110-2170 MHz

C. *Terminal characteristics(M. Cohen)*

The User Equipment is based on the 3GPP Class 3 terminal, with the following possible performances summarized in the following table.

Table 4: Possible terminal characteristics under satellite coverage

UE class	Class 3
Max Tx Power	23 dBm
Antenna gain	0 dBi
Noise figure	4.5, 6 or 9 dB
G/T	-33,6 dB/K
Equivalent G/T under satellite coverage	-36,6 dB/K
EIRP	23 dBm
Equivalent EIRP under satellite coverage	20 dBm

The different Noise Figure values correspond to possible values according to the technological evolution. 6 dB is medium value that can be easily reachable with state of art technology in S band, and is taken as reference.

D. *Channel modeling*

Since narrowband signals are considered, time dispersion effects can be neglected. In [1], Perez-Fontan proposed a three-state channel model, corresponding to line-of-sight (LOS), intermediate shadow and deep shadows conditions. Within each state, the received signal follows a Loo distribution [2], meaning that the signal is the sum of the direct signal and a diffuse multipath component. The direct signal is log-normally distributed while the diffuse multipath component follows a Rayleigh distribution. The direct signal variations are due to non-uniform receive antenna patterns and changes in mobile orientation with respect to the satellite [3].

The received signal is therefore statistically characterized by the mean and variance of the direct signal component, and by the mean power of the multipath component. Databases are provided in [4], [5] and [6] as function of the elevation, considered area (urban, sub-urban, open…) and different receiver antenna directivity (hand-held and car-roof antennas).

A two-state channel model is considered in [7], not necessarily corresponding to LoS and non-LoS conditions. Within each state, the received signal is also the sum of a direct path and a multipath component, following therefore a Loo distribution. A versatile selection of statistical parameters is proposed in order to better correspond with reality.

III. RADIO PROTOCOL IMPACT

There are several specificities to satellites and/or HAPS that require some 5G systems adaptations in order to fully integrate the satellite components. These changes are summarized in Table 5, and impact the different layers of 5G systems, and are not specific to narrowband IoT services exclusively.

At the physical layer, Doppler shift, which is especially high for LEO satellites (up to about ±50kHz) , necessitates to apply margins to avoid out of blocks transmissions. Considering 180 kHz block bandwidth, the terminals shall transmit only in 80 kHz if no compensation is applied. Since a large number of terminals are transmitting simultaneously, it is expected that the full 180 kHz block bandwidth is used, so that no capacity reduction occurs.

In the context of narrowband IoT, where only sporadic traffic is transmitted by a huge number of terminals, random access techniques should be used to avoid high signaling overhead. Moreover, it is then not necessary to cope with the difference in propagation delays between terminals, which are in the order of a few ms for satellite systems. A higher complexity is necessary at the gateway side to detect the received signals since collision may occur and frequency of signals is unknown.

Low PAPR modulations are usually preferable in order to drive the power amplifier onboard the satellite close to its saturation point. However, the amplified signal is here the concatenation of independent signals related to each resource block. Therefore, low PAPR modulations are not critical in the considered context.

A seamless handover between infrastructures is targeted as it uses the same 5G waveform with potential dynamic reconfiguration of the protocols and mechanisms to adapt to each technology.

Table 5: Satellite/HAPS specifics implying modifications of 5G systems for satellite/HAPS operations

Satellite/HAPS specifics	5G system impacted areas	Features to be adapted for satellite/HAPS operations
Propagation channel, interference context, Doppler, propagation delay	Physical layer	Synchronization, initial access, random access, data channels, channel estimations, low PAPR modulations, link establishment/maintenance due
Propagation delay, beam pattern (very large cells)	Layer 2 and above	Protocols timing relationship, Inter Radio Access Technology hand-over (Satellite/Cellular)
Non terrestrial networks at access and/or transport level	Services	5G services/operational requirements
Propagation delay, beam pattern (very large cells), Cross border coverage (anchor point mobility)	System architecture	Policy & QoS management, Mobility management, Session management, Traffic steering, multi home transport, eMBMS, Charging policy

IV. PERFORMANCE ANALYSIS

A. *Air interface assumptions*

Concerning the Air Interface, it is proposed to consider the NB-IoT waveform with :

On the downlink:

- One Physical Resource Block with 12 sub-carriers occupying the fill carrier bandwidth of 180 kHz for Satellite and HAPS

On the uplink

- One single tone, with two possible cases of carrier bandwidth : 3,75 kHz and/or 15 kHz for satellite link
- One Physical Resource Block with 12 sub-carriers occupying the fill carrier bandwidth of 180 kHz for HAPS

It is further assumed that all systems mainly operate in LoS conditions and that 99% availability is required. It should be noticed that reliability mechanisms such as ARQ or HARQ can further increase this availability.

B. *Propagation margin*

As mentioned in Section IV.A, only LoS conditions are considered. Figure 2 represents the cumulative distribution function of attenuation based on measurements performed in [4], considering suburban area conditions with handheld terminals and different elevation angles. Positive attenuation implies that the direct path and the multipath components sum up in phase, leading to constructive interference. To obtain 99% availability, a propagation margin of approximately 9dB has to be taken. Considering lower availability allows decreasing the propagation margin, which could be beneficial if efficient retransmission mechanisms are applied.

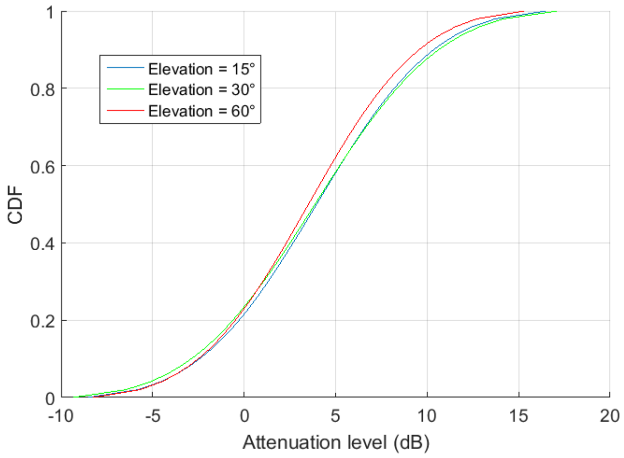

Figure 2 : CDF of attenuation level for different elevation angles

C. *Link budgets*

The different link budgets have been performed using the different platform configurations. The results of the link budgets are of two folds:

- First we present the required EIRP per block of 12 carriers to reach some typical downlink gross bitrate.
- Second, we present the required figures of merit on board to cope with expected bit rates values with sing tone uplink transmission.

For 3GPP class 3 UE, we compute the minimum EIRP and G/T at satellite level to ensure the targeted data rate for an optimum mod/code operating point on both directions.

Table 6: Minimum Required Satellite EIRP (dBW) per 180 kHz carrier

Data rate per 180 KHz carrier	HAPS: 20 km	LEO: 800 km	LEO: 1500 km	MEO: 10000 km	GEO: 36000 km
100kb/s	15,5 dBW	27,8 dBW	32,6 dBW	46,7 dBW	56, 7 dBW
200kb/s	18,6 dBW	33,4 dBW	38,2 dBW	52,3 dBW	62,2 dBW

Table 7: Minimum Required Platform Figure of Merit (G/T in dB/K)

User rate per UE	HAPS: 20 km	LEO: 800 km	LEO: 1500 km	MEO: 10000 km	GEO: 36000 km
1 kbps	N/A	-18,8 dB/K	-13,9 dB/K	0,1 dB/K	10,1 dB/K
5 kbps	N/A	-12,7 dB/K	-7,9 dB/K	6,1 dB/K	16,1 dB/K
10 kbps	-20 dB/K	-10,8 dB/K	-5,9 dB/K	7,1 dB/K	18,1 dB/K

For HAPS, it is possible to increase the data rate to more than 100 kbps for a 10° elevation angle with a G/T of -9,7 dB/K.

The required values given in

Table *6* and Table *7* are in line with current satellite and HAPS technology.

D. Capacity per satellite and HAPS

This section provides an evaluation of the number of users that can be served by km^2 on the satellite and HAPS systems considered. The table below summarizes the assumptions taken to provide this capacity estimation. As the return link is assumed to be the most dimensioning for IoT and M2M communications, the capacity over return link will be computed.

Table 8: Assumptions for capacity computation

System bandwidth	Block size/user bandwidth	Bit rate	Message size	Average message rate	Efficiency of channel usage
30MHz	200kHz/3.75kHz	1.35 kbps	200 bits	1h to 24h	2

We assume that the efficiency of channel usage that can be reached is 2, thanks to repetition and interference cancellation techniques.

The table below summarizes the capacity computation (i.e. the number of users than can be served for a squared kilometer) for all satellite and HAPS systems considered.

Table 9: Capacity computation for HAPS and satellite systems

	Number of users/km^2 that can be served (1 hour average)	Number of users/km^2 that can be served (1 day average)
HAPS	72576	1741824
LEO	2420	58080
MEO	1815	43545
GEO	907	21772

HAPS provides a very high capacity in terms of number of served users and can thus be useful when hot points need to be covered, backed up or extended in terms of capacity. However it has to be mitigated by the fact that a global coverage is not considered here. If a higher number of HAPS is considered, the interference would increase reducing the possible frequency reuse and thus the number of served users per km^2.

LEO constellations naturally provide a global coverage and a high capacity regarding the number of served users per km^2. In comparison GEO can offer half the capacity of a LEO. This system might be useful to extend coverage of terrestrial networks or to complement the terrestrial systems in dense areas.

V. CONCLUSION

This paper has presented the system study to integrate seamlessly in the 5G architecture, satellites and HAPS components using 5G UE for Narrowband IoT services. The study shows that 5G UE can operate at low bitrate through satellite components with minimum configuration update providing a continuity of service and complementing terrestrial infrastructure for narrowband IoT services. With current technologies the capacity that could be provided through satellite or HAPS components permits to reach high density of user served per square kilometer significantly increasing the number of served objects.

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