CAPACITY OF A UMTS SYSTEM FOR AERONAUTICAL COMMUNICATIONS

MIGUEL CALVO RAMÓN, RAMÓN MARTÍNEZ RODRÍGUEZ-OSORIO,
BAZIL TAHA AHMED, JUAN JOSÉ IGLESIAS JIMÉNEZ
Signals, Sistems and Radiocommunications
Universidad Politécnica de Madrid
ETSI de Telecomunicación. Ciudad Universitaria s/n. 28040 Madrid
SPAIN

Abstract: - Current Air Traffic Management and Air Traffic Control systems will experience a demand increase in the following years due to the large number of operating aircrafts. As a consequence, new solution must be studied to overcome this capacity limitation without affecting the performance of such critical services. This paper presents the STAR demonstrator, a project of the European 6 FP whose aim is to show the feasibility of using UMTS W-CDMA for ATM services. One of the advantages of using W-CDMA technology is an increase in the capacity of the system as compared to existing legacy systems. The contribution is focused on the analysis of the system capacity, and simulation results show the increase as compared to legacy analogue systems.

Key-Words: - UMTS, W-CDMA, ATM, ATC, SDR, Capacity, Air Traffic, ENR, TMA

1 Introduction

The forecast is that the present ATM (Air Traffic Management) and ATC (Air Traffic Control) will have their communications capacity saturated by year 2010 to 2015 depending on geographical areas. The capacity limitations of actual VDL mode 2, 3 and 4 systems will imply severe problems of air traffic congestion and security threatens.

Proposed solutions to overcome the saturation of the frequency band assigned to ATM/ATC, such as the reduction of the channel bandwidth to 8.33 KHz, are only valid in the short term. Solutions based on new technologies are required to support the increasing demand of ATM services due to the air traffic increase. Several broadband systems are being proposed for future ATM aiming to increase capacity and support more advanced services.

The UMTS W-CDMA system has been identified as a possible solution due to its inherent high capacity and to the maturity of the technology already deployed in a high number of terrestrial cellular systems around the world.

The aim of STAR project (Secure ATM CDMA Software Defined Radio) [1] is to breadboard a demonstrator to asses the performance of the UMTS W-CDMA technology applied to ATM communications. The members of the STAR consortium are Thales Communications (coordinator), Agilent Technologies Belgium SA, Ericsson Telecomunicazioni S.p.A., IMST, Green Hills Software BV, Universidad Politécnica de Madrid (UPM), Ercom SA, DFS and NLR.

The STAR demonstrator will include the terminal to be mounted onboard airplanes and the terrestrial infrastructure required to provide ATM services. The UMTS W-CDMA system will be adapted to the air-ground link peculiarities and shall be able to provide the QoS requirements defined for the future ATM/ATC services. Changes to the UMTS standards will be minimized to facilitate the adoption of the STAR proposal by the standardization bodies. Fig. 1 shows the STAR system architecture.

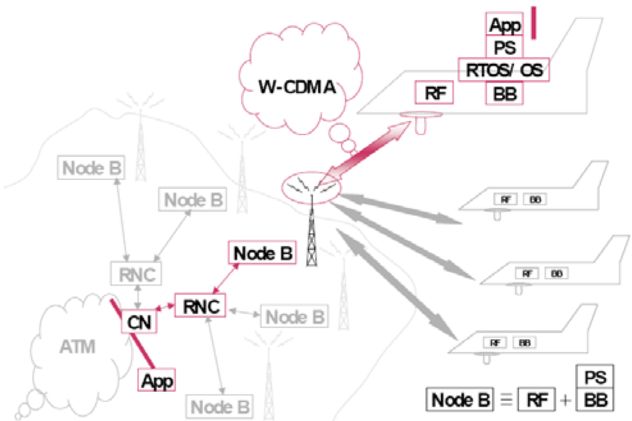

Fig. 1. STAR system Architecture.

The STAR developments will range from the analysis of the changes required to the UMTS architecture to match the requirements of a future ATM system, the assessment of the system capacity, the implementation of a prototype based on software

defined radio techniques and the trialing of the system flying on an airplane.
This contribution deals mainly with the capacity of the STAR system leaded by UPM. The rest of the paper is organized as follows. Section 2 describes more in detail the STAR concept, specially the modifications required to adapt the UMTS system for the provision of ATM services. Section 3 deals with the study of the STAR system capacity and describes the requirements of the calculation tool developed. Obtained results are shown in section 4, while section 5 draws the conclusions.

2 STAR Architecture

Although based on the UMTS Standard defined by 3GPP for terrestrial cellular systems the STAR system introduces significant modifications due to the particular requirements of Air-Ground communications. For instance in those systems the propagation is essentially LOS and the channel fading are less frequent than in the multipath terrestrial environments allowing for a less demanding power control scheme. On the other hand the terminal speed of up to 1500 Km/h is much higher than the 250 Km/h foreseen for terrestrial vehicles and so is the Doppler shift. Those aspects impact in the design of the PHY layer of the demonstrator.
The user terminal onboard airplanes will not experience power limitations or battery shortage. Moreover the requirements of fast establishment defined for some air traffic management services [3] makes feasible the change of access and connection procedures by keeping the terminal always connected with the corresponding modifications in RRC layer procedures.
The demonstrator being developed by the STAR project will be used in real flight trials in Nederland. For the trials only one coverage cell will be used and to simplify the demonstrator protocol stack the functions associated with handover will not be implemented. Also the security and encryption functions of the final system are not required for the demonstrator and will not be implemented.
Following the EUROCONTROL recommendations the demonstrator will be implemented in L Band that is actually being occupied as shown in Fig. 2. As can be seen the frequencies between 960 and 1215 MHz are being used by commercial and military aeronautical communication and navigation systems (JTIDS, SSR, DME, TACAN, GPS-L5, Galileo-E5). The coexistence of those systems with a new WCDMA is difficult. Most of them are based on the transmission of short pulses with a very high peak power. In particular DME transmits 3.5 msec pulses with up to 1 KW peak power [4] that will interfere severely a WCDMA signal using the same frequencies.
For the trials two 5 MHz bandwidth channels are needed in the L band. A deep analysis was performed by DFS to select two channels around 967 and 1153 MHz for uplink and downlink respectively, suitable for the trials and with a frequency separation adequate for duplexing operation. The operational use of those frequency channels will require additional in depth compatibility analysis with JTIDS/MIDS.

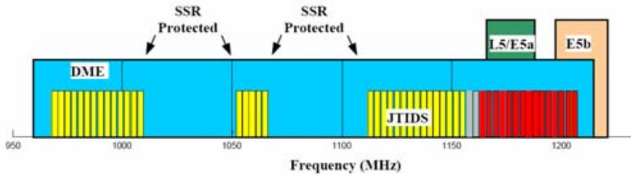

Fig. 2. Use of the aeronautical communications frequency band.

A detailed analysis of the bit rate and delay requirements of the ATS/AOC (Air Traffic Services / Aeronautical Operation Control) as specified in [6], shows that they can be classified as interactive services in UMTS. They can be provided using a single radio bearer of 32 Kbps using a dedicated transport channel DCH in packet switching PS mode. For the purpose of capacity calculations it is also shown that the activity factor is lower than 0.1.
The voice service could be provided using a UMTS conversational type radio bearer. However it is foreseen that this service will disappear in future and meanwhile will be provided by the actual VHF system, so it will not be implemented in the STAR demonstrator. Nevertheless it has been considered in the capacity calculations shown later on in paragraphs 3 and 4.
The characteristics of the services to be supported by STAR are better provided using an IP based communication system so it was decided to use the UMTS Release 7 LTE (Long Term Evolution) [7] network architecture.

3 Study of the UMTS STAR capacity

The capacity calculation of an ATM UMTS based system can be performed in a similar way as it is done in a terrestrial UMTS cellular system. However the following aspects must be taken into account:
• The QoS, Bit Rate and Eb/No of the ATM services are different from the typical values assigned to UMTS services.
• The cells can not be modeled using planar geometries any longer since the planes are distributed in different height layers (flight levels) depending on their trajectories (en route ENR or in landing/taking-off TMA). The cells must then be modeled as volumes [2].

Fig. 3 shows the main scenarios that must be considered for the dimensioning of the system. The different scenarios require different services associated with the different flight phases. For instance the APT (Airport) scenario includes all the plane movements in the airport. For this scenario EUROCONTROL has already selected the WiMax technology and so it is out of the scope of the STAR project. The TMA (Terminal Manoeuvring Area) scenario includes the landing and taking-off phases while the ENR (En-Route) scenario includes the normal flight phase over the cell considered. The different Handovers within and between the different scenarios have been accounted for in the STAR demonstrator.

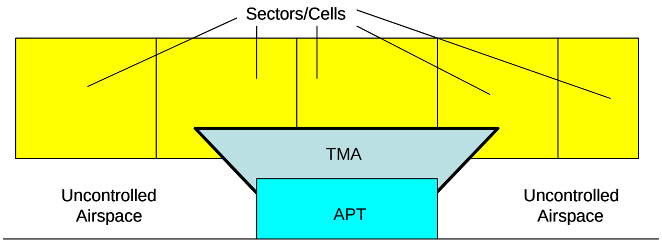

Fig. 3. Flight scenarios.

In the study of capacity the ENR cells can be modelled as cylinders while the TMA cell is part of a cone volume. Cell sectorization can be considered in both scenarios.

The capacity calculation is made independently for the uplink (from the airplanes to the ground station) and for the downlink (from the ground station to the airplanes). The total capacity will be limited by the lower obtained value [8], [9].

In the ENR scenario the flight level ranges from 18000 to 33000 foot (FL180 and FL330, respectively). For the TMA scenario the maximum flight level is 18000 foot (FL180). The separation between the different flight levels is 2000 foot.

A capacity calculator has been implemented using Matlab. A graphical user interface GUI facilitates the selection of the different parameters used in the calculations (see Table 1). The calculator uses the analytical formulations described in [8], [9].

2 Results

Table 1 shows the parameters required for the capacity calculations and also their default values. Some new characteristic parameters are the aircraft density that depends on the separation between flying aircrafts and between flight corridors considered, and the spare capacity reserved to avoid network saturation.

Some of the results provided by the calculator are the following:

- Capacity in terms of number of aircrafts as a function of the cell radius for the selected scenario and link direction
- Number of simultaneous voice and data users (mix capacity) for a given cell size.

General Parameters	
Aircraft Density	0.0046 AC/NM^3
Scenario and flight levels	ENR y/o TMA
Power Control Error	2 dB
Spare Capacity	20 %
Node B Antenna Gain	15 dBi
Aircraft Antenna Gain	2 dBi
Node B Noise Figure	5 dB
Aircraft Receiver Noise Figure	7 dB
Uplink	
Transmit Power	24 dBm
UL Frequency	960 MHz
UL Activity Factor	0.5 (voice)/ 0.1-0.01 (data)
Bit rate kbps	16 (voice) / 32-64 (data)
E_b/N_o	7 (voice) / 9 (data) dB
Downlink	
Transmit Power	43 dBm
% Pilot Power	10 %
DL Frequency	1153 MHz
DL Orthogonality Factor	0.05
DL Activity Factor	0.5(voice)/0.1 , 0.01(data)
Bit rate kbps	16 (voice) / 32, 64 (data)
E_b/N_o	7 (voice) / 9 (data) dB

Table 1. Capacity calculation parameters

Fig. 4 shows as an example the number of voice users in the ENR scenario for the down link (the limiting one). The steps in the graphic are due to the effect of the Earth curvature that affects the visibility between ground station and the aircrafts flying at lower levels. Only the ground stations within line of sight LOS contribute to the intercellular interference. When the cell radius increases the number of ground stations in LOS may decrease producing an step increase in capacity.

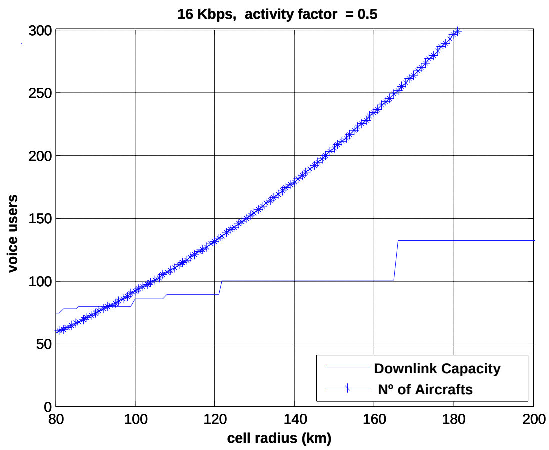

Fig. 4. Number of speech users in the ENR scenario as a function of cellular range (downlink)

In the same figure we have superimposed the number of aircrafts that is foreseen will occupy the cell volume, also as a function of cell radius. As can be seen for a cell radius of 80 Km the number of aircrafts that can be served using voice service is 74.
Fig. 5 and Fig. 6 show respectively the uplink and downlink mixed (voice and data) capacity for the ENR scenario and 80 Km cell radius. In the uplink the maximum number of voice users (no data users) is 102 and the maximum number of data users (no voice users) is 127. Intermediate mixed values are determined by the graphic, for instance 50 voice users and 65 data users would be served. For the downlink the capacity for voice users is 72 and for data the capacity is 92 users. Clearly the downlink limits the capacity of the cell.

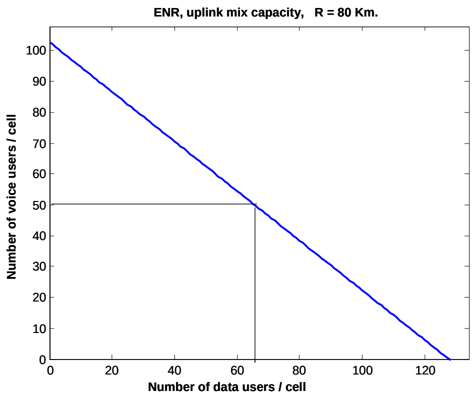

Fig. 5. Mixed Capacity for the ENR scenario (Uplink).

The actual VDL system has a capacity of 100 voice users per cell using a cluster of 7 cells and a frequency bandwidth of 18 MHz. This implies a capacity of 27 voice users per cell per 5 MHz which is clearly lower than the previously obtained 72 voice users per cell per 5 MHz of the UMTS system.

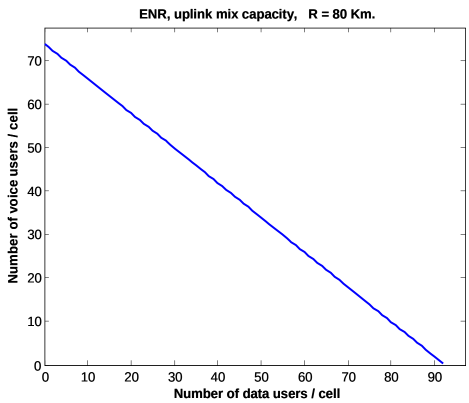

Fig. 6. Mixed Capacity for the ENR scenario (Downlink)

5 Conclusions

This paper presents the STAR proposal for a future communications system for air traffic management services based on the mature W-CDMA technology and its use will facilitate the adoption of the STAR system by the standardization bodies.
The use of this spread spectrum system allows increasing the capacity to overcome the limitations that the actual VDL systems will experience by the future air traffic increase. On the other hand the use of W-CDMA will allow the provision not only of voice services but also the ATC/AOC data services.
The capacity calculations performed for the ENR and TMA scenarios have shown the ability of the W-CDMA technology to support the aeronautical communications of the future. The results obtained for voice, data and mixed services have used the parameter values of the demonstrator that is actually being bread boarded and will be used for the flight trials foreseen in the STAR project.

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