SlotFill – connecting audio/video archives via idle SNG transponders

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This article describes the RAI *SlotFill* system which allows the exploitation of unused SNG capacity for "batch" connections between the RAI Central Archive and remote production centres. The SlotFill system guarantees automatic management of the satellite transmissions, avoiding any interference to the "high priority" SNG services.

RAI has recently developed a digital "Fast" audio/video archive, which has now started continuous programme storage (News, Fiction, Talk Shows, Sport etc.) from the three RAI television networks. This archive – named "Fast" because of the relatively low MPEG coding bit-rate (typically 10 Mbit/s) – is intended as a medium-quality source in TV production which does not require complex post-processing.

A Multimedia Catalogue helps programme retrieval by means of content descriptors which are compatible with conventional web browsers. The descriptor *Textual description* includes, for example, the programme title, date of production, author's name and a summary, while *multimedia description* includes key frames and highly-compressed video and audio.

The RAI Fast Archive and the Multimedia Catalogue are located in Rome; therefore easy access from the four RAI production centres in Rome, Milan, Turin and Naples is an important system requirement. Once the wanted material has been identified and selected from the Catalogue via the Intranet, the central Fast Archive must be able to transfer the A/V files to the remote user; for example, by using high-capacity digital networks such as SDH, ATM and satellites.

RAIWAY – the controlled company which runs the transmission and broadcasting networks on behalf of the RAI services – leases satellite transponders for SNG applications on a yearly basis, so that the immediate availability of the channel is guaranteed when necessary. SNG traffic is invariably a high priority and takes place in real time, but the actual exploitation of this satellite resource is, on average, very low (basically less than 50% of the time), especially during the night.

The new *SlotFill* system – developed by the RAI Research & Development Innovation Centre (CRIT) in co-operation with the RAI Production Division – allows the exploitation of unused satellite capacity for the reliable delivery of audio/video files from a centralized archive to remote studio production centres. At the transmitting site, the SlotFill system guarantees automatic management of the satellite transmission, avoiding interference to the "high priority" SNG service. As soon as an SNG signal accesses the satellite transponder slot already in use by the SlotFill system, the control unit cuts off the "low priority" archive connection. When the slot becomes available again, the archives connection is restored and the lost data packets (if any) are recovered.

The main user requirements have been identified in co-operation with the RAI Production Division. The SlotFill system shall:

- ⇨ allow transparent audio/video file transfer by satellite;
- ⇨ not interfere with the main SNG service, both under normal operating conditions and under any foreseen emergency situations;

Abbreviations

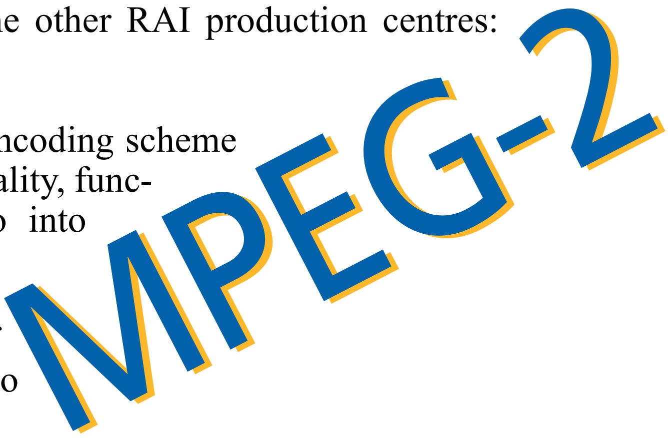
8PSK	Eight-phase-shift keying
16-QAM	16-state quadrature amplitude modulation
ATM	Asynchronous transfer mode
BMC	Broadcast management centre
DSNG	Digital satellite news gathering
DVB	Digital Video Broadcasting
DVB-S	DVB - Satellite
DVB-TS	DVB - Transport Stream
ETSI	European Telecommunication Standards Institute
FM	Frequency modulation
FTP	File transfer protocol
IF	Intermediate-frequency
IP	Internet protocol
LAN	Local area network
MPE	(DVB) MultiProtocol Encapsulation
MPEG	Moving Picture Experts Group
NTSC	National Television System Committee (USA)
PAL	Phase alternation line
PCI	(Intel) Peripheral Component Interconnect
PID	(MPEG) Packet Identification Number
PSTN	Public switched telephone network
QPSK	Quadrature (quaternary) phase-shift keying
RAI	*Radiotelevisione Italiana*
RF	Radio-frequency
SCC	SNG control centre
SDH	Synchronous digital hierarchy
SECAM	*Séquentiel couleur à mémoire*
SNG	Satellite news gathering
STC	Satellite transmission control
TCP	Transmission control protocol
UDP	User datagram protocol
WAN	Wide-area network

- not require transmission procedure modifications to the main SNG service;
- be capable of fully automatic operation;
- provide error and packet-loss recovery;
- be based on international standards, such as DVB-DSNG for transmission and DVB-MPE and IP for the transport protocols;
- be capable of flexible operation, in order to exploit the available capacity on various frequency slots (e.g. 9 MHz) of a satellite transponder.

The RAI audio/video archives

The main target of the Fast Archive system is the realization of an agile and economically-viable production tool, suitable for news, magazine and thematic channels which require simplified editing processes. The Fast Archive is being progressively loaded with RAI on-air programmes and with other A/V production material which is available in the "full-quality" archive. Therefore the Fast Archive may also act as a "disaster recovery" system for feeding directly the broadcasting networks, and as a "hot archive" dedicated to news channels or new multimedia services.

The Fast Archive technology is based on large video servers, using high-speed data storage and networking, and MPEG encoding/decoding. Its location is centralized in Rome, with remote access from terminals at the other RAI production centres: Milan, Turin and Naples.



The use of a 10 Mbit/sec MPEG-2 422P@ML encoding scheme was adopted after a detailed analysis on video quality, functionality and system performance, taking also into account the storage and network architecture.

The system design target is the management of up to one hundred local and remote clients. Two different service classes have been identified:

- "best service", available only in the Rome area, which guarantees the possibility of accessing a 20-minute video clip in less than 7 minutes;
- "batch service", for material to be used on a scheduled basis.

The system's target storage capacity is 500 000 hours (corresponding to about 1 million video clips).

For local users within the Rome area, the transfer of video clips is made using *file transfer* via a Fibre Channel network (fast FTP). Future system software releases will probably allow for *file streaming* methods, thus permitting the preview of video material before the end of the file transfer operation.

Peripheral systems in the other production centres (Milan, Naples and Turin) are scaled-down versions of the central Fast Archive in Rome, and include a video server with co-decoding and storage resources. Remote users will be able to reach all the archive material – accessing the locally-stored content immediately, and downloading the central archive material via WAN, radio-link or satellite connections. User requests may be satisfied in batch mode, when links are free from normal traffic (i.e. during the night).

Fast Archive users are divided into priority classes, defined by the maximum amount of material that can be requested and the maximum delivery time. Highest priority will be given to news production users, which typically need few short clips, but with short delay. Lowest priority will be assigned to programme production users, who usually ask for a lot of material, but may accept a scheduling delay of several days. The system will recognize users during "logon" procedures, and will consequently assign them the most appropriate transmission resources and the due priority.

SNG transponders

In modern-day broadcasting – dominated by increasing competition – the real-time acquisition of news events (e.g. sports meetings, interviews, concerts, calamities), in both the domestic and international environments, is a major factor in the search for audience ratings. In this context, SNG provided by light-weight transmit terminals with small antennas (e.g. 90 to 150 cm) is the solution for establishing rapid connections between outside broadcast vans and the TV studios, without requiring local access to the fixed telecom network. In Europe, the TV contribution links by satellite are commonly in "Ku" Band (14 - 14.5 GHz transmit, 10.71 - 12.75 GHz receive).

Analogue SNG systems – for TV transmissions in PAL, SECAM and NTSC using frequency modulation of the sound – are progressively being replaced by digital SNG systems (DSNG), because of their operational advantages. Among these advantages, significant factors are the "miniaturization" of the up-link terminals, the lower power (EIRP) required and the more efficient use of the frequency spectrum. This permits multiple signals to be simultaneously transmitted through satellite transponders, significantly increasing the flexibility of transponder access and reducing the cost per channel. The inherent flexibility of the digital solution allows the fulfilment of different quality requirements for the satellite transmission of news, sports events and entertainment programmes, by operating the audio/video compression algorithm at the appropriate bit-rates. Moreover, the ruggedness of digital systems against noise and interference offers a constant picture and sound quality at the receiving site. In 1997, the DVB Project developed a new specification for DSNG [1][2], based on the DVB-S broadcasting system, but with a number of new features, such as selectable modulation and coding schemes, and MPEG-2 422P@ML picture coding.

While direct-to-home satellite services usually allocate a single carrier per transponder, DSNG services split the transponder bandwidth into several "slots", so that the transponder resources are shared between multiple carriers (see the example in *Fig. 1*, where a 36 MHz transponder is split into four 9 MHz frequency slots).

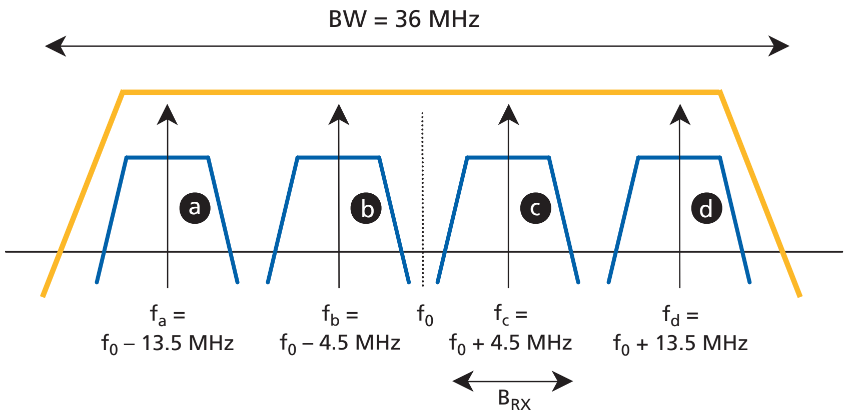


Figure 1
DSNG signal allocation in four frequency slots.

Table 1 shows examples of DSNG terminal characteristics for typical service configurations in Italy. The link design has been optimized for small up-link terminal antennas.

Table 1
Example DSNG connections in Italy [a].

Signal		Up-link terminal				Rx station
Useful bit-rate (Mbit/s)	Mod. & coding	Type	HPA Power [b] (W)	Antenna diameter (m)	EIRP (dBW)	Antenna diameter (m)
8.45	QPSK 3/4	Flyaway	70 / 110	0.9	56/59	3
15.36	8PSK 5/6	Vehicle	120 / 230	1.5	63/66	6

a. Four digital signals in a 36 MHz transponder; 9 MHz frequency slots.
Satellite: EIRP at saturation; 46.5 dBW to Rome, OBO (total); 4 - 6 dB.
Service availability: 99.9% average year, K & L climatic zones.

b. Power at saturation; operational OBO = 2 dBi.

The SNG traffic on a transponder shows a strong daily variability: the traffic is very high before news programmes and sport events; it is medium during the rest of the day and very low during the night. A simplified daily traffic model could be the following: 100% of slot occupation for 8 hours, 50% of occupation for 8 hours and no traffic for 8 hours. Therefore about 50% of the transponder capacity is generally unused, but it is rather impossible to exploit this spare capacity using real-time traffic since, typically, SNG transmissions cannot be delayed.

The SlotFill system has been designed to exploit this residual capacity by using non-real-time traffic (batch mode) to feed the remote terminals of the RAI Fast Archive system.

General architecture

SlotFill is a high bit-rate digital communication system which occupies a temporarily empty slot in a given SNG transponder. The SlotFill carrier is automatically released as soon as an SNG service (analogue or digital carrier) tries to access the slot itself. Such functionality is managed by the Satellite Transmission Control (STC) located at the SlotFill transmitting station premises, without requiring any modification to the equipment and stations used by the main SNG service. *Fig. 2* represents the general architecture of the SlotFill system, which is made of the following building blocks:

Satellite up-link: essentially based on a DVB transmitting station. The transmission signal may be either a narrow-band DVB-S carrier (QPSK modulation) or, in the case where higher spectral efficiency is required, a DVB-DSNG carrier (8PSK and 16-QAM modulation schemes).

Satellite Transmission Control (STC): this is the "core" system which controls the transmission of the SlotFill signal. It continuously checks the transponder status, in order to find an unused slot (the start of the SlotFill transmission) and to detect other transmissions on the same slot (the end of the SlotFill transmission).

Broadcast Management Centre (BMC): this is the subsystem which allows the high-speed delivery of audio/video programme material through the satellite link, using DVB and IP technologies. The BMC receives transmission requests from the Central archive and manages the file transfer according to specified procedures.

Receiving Terminals (TR): these terminals are based on a PC equipped with a commercial PCI DVB-S receiving board. In the case where DSNG modulation schemes are used, an external professional receiver is necessary since PCI receiving cards are

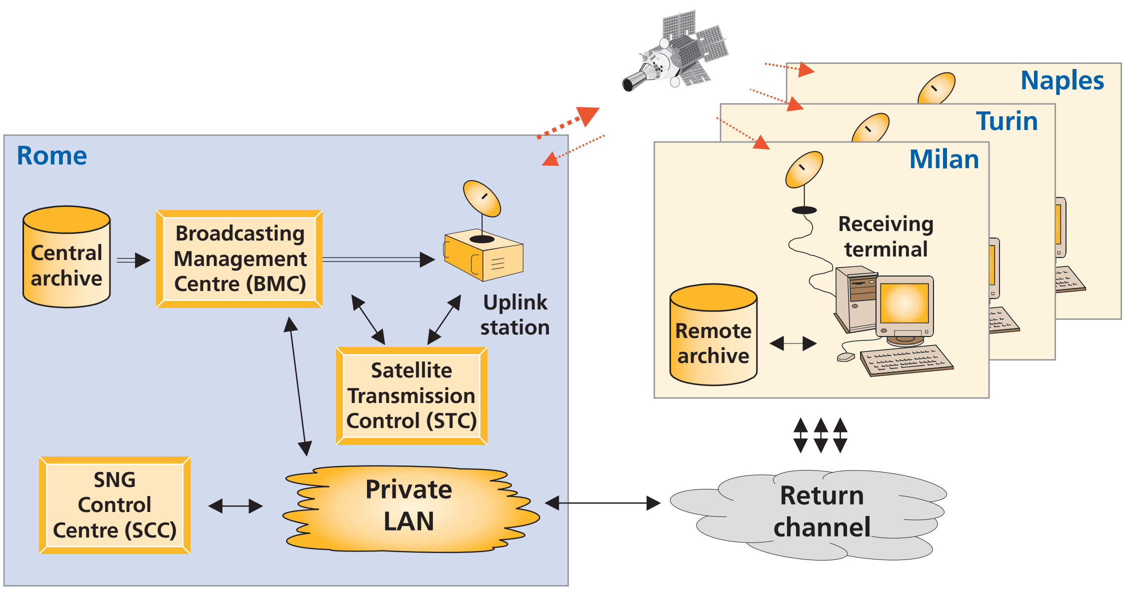


Figure 2
General system architecture of SlotFill.

not currently available. Data streams received from the satellite are then transferred to the Remote archive through a LAN connection.

Return channel: appropriate protocol layers perform both session management and the recovery of lost packets. These functions are achieved by means of a return channel based on low-capacity terrestrial links (Intranet, Internet, PSTN).

SNG Control Centre (SCC): this infrastructure, already operating for the SNG services, has the main task of allocating satellite capacity (slots) to the SNG vehicles, according to the requirements of the programme production. The introduction of the SlotFill functionality does not require, in principle, any modifications to the SCC rules of operation (e.g. the booking of satellite capacity). However, by applying a smart slot-allocation strategy to the SNG services, the probability of them wanting to occupy the slot used by SlotFill may be reduced (especially in the *static* version – see below), thus improving the throughput of SlotFill.

The SlotFill operational procedure may be summarized as follows:

1) A remote user of the Archive can search and request audio/video clips using the Multimedia Catalogue; this operation is accomplished through the Intranet.
2) The request is forwarded to the Central archive.
3) the Central archive requests the Broadcast Management Centre to deliver the selected video clip to the remote site, according to a set of parameters (schedule time, priority, etc.).
4) The audio/video file, previously transferred to the Storage unit of the BMC, is transmitted by satellite when a frequency slot becomes available.
5) The data stream is captured by the receiving terminal and transferred to the Remote archive; management of the session is performed through the Return channel (packets lost due to channel errors or to an SNG interruption are requested to be re-sent).

The system offers a very high reliability in terms of correct file reception via satellite. Nevertheless, due to the fact that SNG is the primary service and SlotFill is the low priority one, it is not possible to guarantee a maximum delivery time. Therefore the users may be provided with only a rough estimation of the delivery time, based on statistical information on the transponder usage.

Broadcast Management Centre (BMC)

The Broadcast Management Centre is mainly based on DVB and IP technologies. It comprises a data server, a DVB gateway, and switches and routers for the interconnection of the other subsystems over a Private LAN. In fact, network connections with the Central archive and with the Satellite Transmission Centre are also necessary: in particular, the link with the Central archive should support high data rates in order to allow high-speed transfer of A/V files for subsequent transmission. *Fig. 3* shows the block diagram of the BMC.

The DVB gateway operates by taking IP datagrams from the network (LAN) and inserting them into DVB-TS packets according to the MultiProtocol Encapsulation (MPE) profile defined by DVB [3]. The DVB gateway can be configured to associate each logical data flow (characterized by IP address and/or MAC address) with one or more Transport Stream PIDs (Packet Identifiers), according to the allocated bandwidth.

The Storage unit allows temporary buffering of the audio/video files coming from the Central archive, before their transmission by satellite.

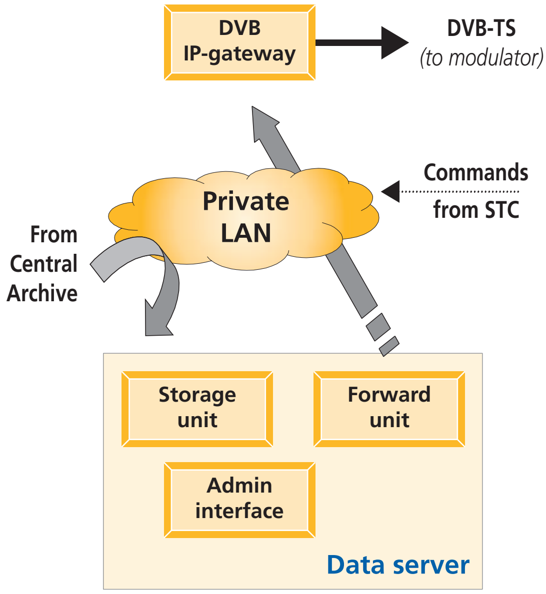


Figure 3
The Broadcast Management Centre.

The Forward unit creates the logical data flows, addressed to the remote terminals, which are then processed by the DVB gateway (unicast data streams). The delivery of files is based on a BTFTP (Broadcast Trivial File Transfer Protocol), inserted over UDP/IP. The BTFTP, developed by CRIT, allows efficient and reliable file transfer over uni-directional broadcast channels, without a permanent return channel. In this protocol, the return channel is activated only when the transmission has been affected by packet losses, and a re-transmission request is forwarded from the remote receiving terminal to the BMC. As an alternative, the file transfer could also be operated through a standard FTP session, based on the TCP/IP protocol. In this case a fast return channel must always be kept active and the loop delays through the satellite may significantly limit the system throughput.

The overall management of the Data server is governed by an Administration interface, which translates the commands received from the Central archive and allows system configuration. The Data server also receives commands from the Satellite Transmission Control (STC), signalling via satellite the availability of an empty slot.

Four commands have been defined: Start, Pause, Resume, Stop. The Start command indicates that the slot has become free, and the transmission may start. The Pause command interrupts the transmission of files, during a “collision” with an SNG signal. The Resume command restarts the file transfer after a pause, repeating also the last N seconds of each file. This “rewind” function of the Forward unit may be necessary to recover corrupted / lost packets, after a “collision” with an SNG signal.

Satellite Transmission Control (STC)

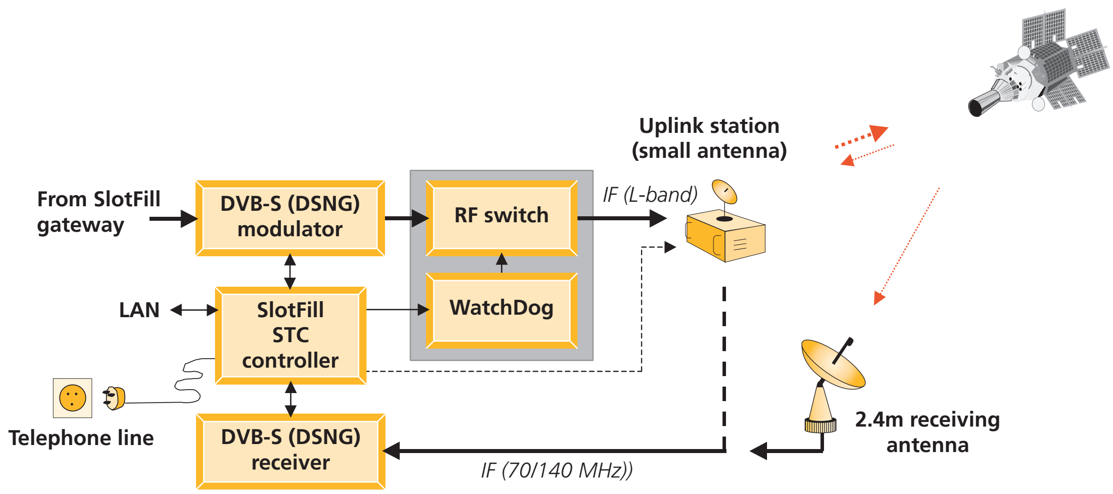


Figure 4
Schematic of the Satellite Transmission Control.

Access to the satellite and all the related functions are managed by the Satellite Transmission Control (STC) – see *Fig. 4*. The transport stream is fed to a DVB-S or DVB-DSNG modulator, able to operate in narrow-band modes (symbol rates of about 6.5 Mbaud in a 9 MHz slot). The basic transmission modes – allowing a good trade-off between ruggedness against noise and high bit-rate – are QPSK 3/4 or 2/3. This provides for useful bit-rates of the order of 8 - 9 Mbit/s in a 9 MHz slot.

Higher efficiency modulations such as 8PSK and 16-QAM might offer higher bit-rates (up to 15 - 20 Mbit/s), but would require very large antennas (7 - 8 m diameter) and specific “gain setting” of the transponder, incompatible with the DSNG service [1].

The modulator IF-output signal feeds a standard satellite up-link station, through an RF switch. A DVB-S (or DSNG) local receiver is required in order to monitor the signal on the satellite slot. The required receiving antenna diameter is around 2.4 - 3 m (see *Table 1*), while the transmit antenna may be smaller (about 0.9 m).

The SlotFill STC controller is a computer-based equipment, interfaced to the modulator, receiver, RF switch and, optionally, to the up-link station; a LAN connection allows for communication with the Data server in the BMC. A telephone-line interface is provided to give SNG operators the possibility of remotely stopping a SlotFill transmission without the need for an Internet connection.

As a safety measure against failures of the STC controller, a “watchdog” device is connected to the RF switch, in order to automatically cut off the transmission if needed. The SlotFill system can be implemented at different levels of complexity and cost. The simplest version operates on fixed pre-assigned frequency slots (*static* SlotFill).

In the most complex solution, the system can operate on different frequency slots (*dynamic* SlotFill), changing both the frequency and the transmission symbol-rate.

In the most general case (dynamic), the STC performs the following steps:

- **Search phase**: the receiver scans the available transponder slots for empty ones.
- **Transmission phase**: once an empty slot has been identified, its position is notified to the BMC, which communicates the transmission frequency to the receiver. Then the transmission starts; the slot status is continuously checked for possible collision with an SNG signal. In this case, the controller immediately cuts off the transmission, and stops the Data server. The system returns to the search phase.

Moreover, the transmission phase can be terminated also by a command from (i) the server, (ii) a remote SNG station operator via telephone keyboard and (iii) the SNG Control Centre (SCC) through a network connection (Intranet).

The detection of a collision with an SNG signal may be performed by measuring the error rate detected by a local receiver: Viterbi and Reed-Solomon decoders may offer this feature. However, a better reliability may be achieved by checking the DVB transport stream, on private PIDs. This method also has the advantage of allowing the SlotFill signal from other DVB-DSNG-compliant carriers to be recognized.

In the static implementation of SlotFill (i.e. without frequency agility), the STC system can be significantly simpler and cheaper than in the dynamic implementation. In the dynamic case, the up-link station – which includes an IF-to-RF up-converter – must be interfaced to the controller in order to become agile in frequency. Moreover, a communication protocol between the STC, the BMC and the receiving terminals has to be set up in order to exchange information about the new slot which is to be used when the previous one has become busy. Obviously, frequency agility is also required in the receiving terminals.

Conclusions

A fully operational SlotFill prototype (with static frequency assignment) has been developed by CRIT and was demonstrated at the Montreux 1999 exhibition. The design of the final platform is being improved and completed in line with the requirements identified by the RAI Production Division.

Acknowledgements

The authors wish to thank B. Sacco (CRIT) and N. Minnaia (RAI Production Division) for their considerable assistance in preparing this article. Thanks must also go to RAI colleagues L. Boch, P. Casagranda, R. Del Pero, A. Messina, M. Rossini and L. Vignaroli who contributed to the prototype implementation of SlotFill.

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Dr Morello is a member of several international EBU, ITU-R and CEPT groups and has participated in various EUREKA and ACTS projects. He was Chairman of the DVB ad-hoc groups which defined the technical specifications for the DVB-S and DVB-DSNG systems. He is the author of various technical and scientific articles and has presented numerous papers, relevant to his studies and research work, at national and international events.

Gino Alberico graduated in Electronic Engineering from Turin Polytechnic in 1987 and, the following year, joined the EMC Group of Aeritalia where he was involved in the design of a computerized system for generating arbitrary radar signal patterns for testing purposes. Later that year he joined RAI Research Centre, where he is now responsible for the "Multimedia and Digital Platforms" group, dealing with digital broadcasting platforms and new multimedia services over broadcast channels.

Mr Alberico contributed to the ETSI specification for the 34 - 45 Mbit/s (4:2:2) television system. He has also contributed to the EBU and ETSI activities concerning the specification of the Digital Audio Broadcasting (DAB) system. He and his group are now heavily involved in the technical evaluation of the DTT trials in Italy, in the deployment of multimedia and datacasting services over broadcasting channels, and in the development of interactive television applications aimed at DVB set-top boxes, with particular interest in the MHP open platform. He is also author of many technical and scientific publications, presented at international conferences and exhibitions.

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