Flexible Heterogeneous Satellite-Based Architecture for Enhanced Quality of Life Applications

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ABSTRACT

The future pervasive communication ecosystem can improve and enhance the quality of our everyday lives by increasing comfort and safety perception, and improving interaction and conditions of activities: remarkable quality and performance will be afforded by the synergistic use of communication, positioning, and monitoring techniques, provided by means of meshed heterogeneous architectures based on satellite and terrestrial segments. In such a scenario satellite communication will represent the missing link of the evolution of services. This article aims to describe a flexible architecture that could be adopted in the future system and discussing the open points in the development of the system as well as of its single building blocks.

INTRODUCTION

Looking ahead at the coming years, a pervasive communication ecosystem [1] will be realized by integrating the main systems. In this scenario users will interact with services more than with different technologies in a continuous search for high capacity, high reliability, flexibility, adaptivity, and innovative applications. Eventually based on location and context awareness, this will be fully supported.

The improvement of everyday life will be the result of a many-fold set of actions involving several different aspects of human behavior. Information and communication technology (ICT) can ease this process by allowing the growth of information exchange: in order to follow users during their daily movements, satellites will represent the missing link of the evolution of services.

The “big picture” of how telecommunications can improve our lives in the near future is represented in Fig. 1. There are five main location contexts where we spend the majority of our life. At home, a smart environment can increase our comfort, assist elderly people, and increase our perception of safety when sick [2, 3]. In smart connected workplaces, collaboration tools and information exchange increase both productivity and working conditions [4]. Entertainment applications, automated driving, and road assistance [5] can dramatically increase the quality of our time spent commuting. Social activities can also benefit from new entertainment applications characterized by real-time interactions and immersive experiences. Even the global environment, considered as the place where we spend all our life, can be improved by technologies that are able to help us identify our location, to constantly monitor the health status of Earth’s surface, and identify potential risks or hazards.

Citizens are able to share and receive information if they are well equipped with advanced mobile and web-based communications technologies (e.g., smartphones able to send messages, high-resolution images, and high-definition videos). Past crises have clearly demonstrated intensive use of short message service (SMS), which requires lower capacity than voice, and Internet-based messaging (e.g., posts on social networks, text messages), which is boosted by cellular services or the availability of WiFi access points (APs). This trend highlights citizens’ empowerment as central information providers because they become the first in situ sensors, able to detect and monitor incidents. The use of innovative smart technologies (platforms, devices, services, and applications) could significantly improve situational awareness for public safety organizations (PSOs) and citizens and, as a consequence, provide actionable intelligence and bolster effectiveness and performance (e.g., act faster, react better, and build a safer and more secure society).

This article aims to describe a future flexible architecture that could be adopted in future systems with the goal of providing innovative services. The article is organized as follows. The next section reports some example application scenarios. Then a current satellite-based architecture, which can be considered as a basic pillar for the definition of the future platform, is introduced, and the future flexible proposed architecture is discussed. Next, we focus on open issues and outlooks that need to be considered for the development of such an architecture. Finally, conclusions are drawn in the final section.
POTENTIAL APPLICATION SCENARIOS

The flexibility and reconfigurability features of the proposed architecture, described in the next section, can support a large variety of services for different potential application contexts. Although already existing services may not be able to exploit all the functionalities provided by the architecture, new advanced services can be developed relying on their integration. Some examples are reported in the following.

E-HEALTH AND WELL BEING

The proposed architecture can provide solutions to some of the main problems related to the management of many patients in a care environment (hospital, rehabilitation structure, etc.) during all the different care phases and to the remote care of convalescent or home patients (for diseases such as diabetes and hypertension). The patient can be assisted “transparently” at any time through adaptive interactions between smart objects (sensors, drugs, doctors’ terminals, patients, relatives, and pharmacies) that have received suitable localization and context information: the monitoring of some main parameters allows immediate assistance in case of necessity or if access to specified building areas is aided or blocked based on established relations helping the necessary patient mobility. The transparency to the user, flexibility, and cooperation between the patient, the objects, and the network are of utmost importance in the disease context and can be specifically tailored to the assistance of patients affected by specific problems or pathologies (e.g., wandering dementia). The specific operational modalities of the platform (user-oriented, object-driven, and network/context-enabled) can provide suitable solutions to the different applications.

Another widespread field of interest that can be addressed by the proposed architecture is well-being systems and sport activities: in particular, people practicing a sport can share information about their activities and experiences while also being connected and monitored by means of wearable devices.

The specific services for these scenarios are summarized in Fig. 2.

PUBLIC SAFETY

Every member of a rescue or safety team is equipped with a portable radio transceiver, with advanced integrated navigation/communication (NAV/COM) capabilities. Navigation capabilities are necessary to determine the terminal position, using both Global Navigation Satellite System (GNSS) services and, in the absence of a satellite radio link, terrestrial network-based positioning methods. The requirements of radio communication systems for emergency rescue applications [6] shall ensure that the required information is available to the correct person at the appropriate time: communications must be timely, relevant, and accurate since this implies the efficiency of the emergency operations among several authorized emergency personnel teams.

MOBILITY

In this case, a driver obtains information on traffic conditions not only from a public or private communication network and from other roadside objects, but also from other drivers and
vehicles by means of the establishment of relationships among the cars that usually cover the same track and the consequent exchange of information; hence, by optimizing the travel time and fuel consumption, the best paths can also be chosen in the presence of traffic congestion. Moreover, this scenario also encompasses the exchange of information for traffic, parking, detours, accidents, and so on.

**SATellite-BASED ARCHITECTURES**

As a matter of fact, technological and societal changes push toward a future in which telecommunication entities and architectures will be integrated with heterogeneous systems with localization and sensing capabilities, and people and intelligent objects will cooperate as in social networks with the goal of providing services. This trend is also enforced by the ongoing Internet of Things (IoT) development, in which pervasive connection of the environment will facilitate positioning, sensing, communication, and interaction capabilities never experienced before.

The required degree of interaction and interoperability among the various communication components is enabled by forging a new integration substratum, which will play a key role in the definition of the next architectures. These components are highlighted in the lower part of Fig. 1. Particularly, satellite communication, navigation, and monitoring systems are envisaged to play a crucial role in the definition of specific functionalities in the framework of the provision of security, transportation, enhanced quality of life, and institutional services.

As for the integration of localization and sensing capabilities, terrestrial and satellite communication subsystems and intelligent objects and networks will have to cooperate in order to provide enhanced value location-based services.

The proposed heterogeneous network architecture can be seen as a general system that is able to self-adapt to the available network resources, to guarantee the adequate quality of service level required by the target applications and to enable new pervasive advanced services. The high degree of flexibility allows the identification of a large variety of application contexts, where the different components of the described architecture may be selected from the different technology domains and be used.

**CURRENT ADVANCED HETEROGENEOUS ARCHITECTURES**

As a starting point, some examples of current satellite-based advanced architectures are briefly described, highlighting their relevant features. In particular, the e-health and emergency contexts are considered, since they represent two significant scenarios where network availability and quality of service (QoS) have to be guaranteed even in critical situations.

**E-Health System Architecture** — In the e-health context a heterogeneous satellite-based system architecture allows distributed medical competence to be shared and the integration of clinical information, contributing to the quality of medical care for both professional and self-care purposes. In this framework it is worth mentioning, as an example, the KosmoMed project [7]: the system architecture is designed for the provision of professional medical services to allow specialists, health care operators, and patients to access an interactive platform that is able to support different kind of applications such as real-time tele-diagnosis and tele-consul-
In order to support the development of new advanced services that also exploit multiple combinations of existing ones, the proposed system architecture is based on integration of localization, communication, and sensing/monitoring.

Emergency Heterogeneous Architectures —
In the whole cycle of emergency situation management, and particularly during the response and mitigation phases, the availability of a system architecture that integrates localization, communication, and sensing capabilities leads to remarkable gains in terms of speed of response, and completeness and effectiveness of intervention. The exploitation of these benefits can be favored by the adoption of reconfigurable and interoperable devices. The baseline network architecture and proposed solutions for the integration of localization and communication functionalities, which have been studied in the framework of the SALICE project [8], represent an interesting starting point for both the definition of a general system architecture and more sophisticated devices to be used in critical operational conditions. In detail, the definition and tested implementation of the reconfigurable NAV/COM terminal based on software defined radio (SDR) technology aimed at providing emergency operators (first responders) means to achieve localization information even in light indoor conditions, which are characterized by partial visibility of satellite navigation systems. This result represents an interesting application example of the integration of two of the three main pillars of the architecture proposed in this article. As a result, the functionalities provided by a flexible and heterogeneous architecture can be exploited in the context of emergency situation management. The adoption of satellite is essential for both communication and navigation purposes: mainly thanks to its resilience to terrestrial damage, its broadcast capability over a large area, and its multiple functionalities, the use of satellite is particularly suitable for supporting emergency management activities.

Future Flexible Architecture
In this section the archetypical architecture to be adopted in future heterogeneous networks is discussed. As shown in the lower part of Fig. 1, the implementation of applications is currently bound to the available access technology for each specific context. The result is that the integration of services is only possible at the client level (i.e., smartphones, car computers, navigation devices), with heavy limitations on potential services. The evolutionary path requires a deeper level of integration of the satellite components as well in order to move services over networks, rather than moving clients over services. This approach is aligned with the recent trend of separation of the control plane from data transport in software defined networks (SDNs) [9]. The migration toward network virtualization functions allows fine-grained definition of available services on a per-user basis, introducing new cross-tier interactions among information domains (user position, user context, user environment, etc.).

In order to support the development of new advanced services that also exploit multiple combinations of existing ones, the proposed system architecture is based on integration of the aforementioned functionalities: localization, communication, and sensing/monitoring. This result can be achieved by the definition of a flexible, scalable, and reliable heterogeneous architecture, which includes the satellite component as a key element. Satellite GNSS, communication, and monitoring systems are all parts of the proposed architecture together with different terrestrial components. This meshed architecture enables cooperation among satellite systems and terrestrial ones with the goal of benefitting from the capabilities of each system. In particular, focusing on localization, communication, and sensing/monitoring functionalities, the capabilities of each single subsystem can be improved by exploitation of the features of the others, also in critical contexts. As an example the use of terrestrial communication technology can help the positioning of a GNSS system in non-line-of-sight (NLOS) visibility conditions (cooperative localization techniques). A synergistic use of the single functionalities can be afforded by the use of the most recent cooperative, cognitive, opportunistic, and context- and location-aware technologies. Moreover, a fully interoperable architecture will be enabled by the distributed system intelligence and suitable interfaces.

This concept is depicted in Fig. 3, which shows the baseline system architecture, where the enabling technologies and systems of each of the three main functionalities to be integrated are highlighted (left of the figure):

Communication: The integration of the terrestrial (long- and short-range networks) and space (satellite, unmanned aerial vehicle—UAV) segments can guarantee the availability of network resources in several operational conditions, which include critical situations.

Localization: The adoption of both satellite and terrestrial localization systems is considered for supporting different location-based services even when the line of sight to the satellite is obstructed. This includes the use of the Galileo system together with its new services.

Sensing/monitoring: Environmental sensing and monitoring systems based on integration of information coming from satellite systems and terrestrial sensor networks or sensors installed in UAV platforms can be used for different purposes, such as safety and security applications.

The proposed architecture aims at integrating already existing and future network technologies and standards, exploiting their complementary features (e.g., in terms of coverage extension,
capacity, broadcast/broadband capabilities, resilience, and reliability). It enables users to access (bottom of the figure) multiple services managed by the service provider control center (top of the figure) by using any kind of enabled devices (i.e., fixed, portable, and handheld ones) as the interface with the distributed infrastructure.

The interactions among the different network entities of the overall architecture are supervised by the system intelligence, which, acting under the paradigm of machine-to-machine communications, manages data gathering, exchange, and control by implementing advanced solutions. Some of them are:

• Cognitive and cooperative systems for improving physical and network layer operations
• Security mechanisms
• A middleware architecture for the exchange and management of data in a distributed applications context
• Social networking solutions for supporting the adoption of distributed computing algorithms based on the usage of existing and new technologies for social interaction

In the architecture advanced and assisted localization techniques based on the use of GNSS are supposed to exploit additional information by means of a cooperative approach among users. System intelligence will support the interoperability of the sensor networks with the communication systems, so allowing context-aware capabilities of the system. In this general framework of reconfigurability, cognitive and cooperative paradigms are key elements for achieving the benefits which are guaranteed both at the transmission layer and at the network layer: particularly, the cognitive approach shall be focused on both distributed sensing and the definition of a cross-layer solution with QoS. The use of the cooperative paradigm can act as a booster to provide general and ubiquitous services.

It is worth highlighting that the proposed architecture shall not support only the integration of the information coming by different heterogeneous systems/services (e.g., navigation, monitoring), but will aim at the integration of the capabilities of each subsystem for the development of innovative and advanced techniques to be used for system performance improvement in all situational contexts.

**Open Issues**

In this section, some important themes and the relative open points for the development of the future heterogeneous ecosystem as well as its single building blocks are reviewed. Moreover, some possible countermeasures are proposed together with a description of the main trends and growth outlook.

**Localization**

Focusing on localization, an important support to enhanced-value location-based services can be identified in the integration of GNSS and Dead

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Figure 3. Proposed baseline architecture.
expected that in the near future the introduction of higher-resolution video services will drive the need for more efficient transmission technologies in Ku- and wideband Ka-hand transponders even further. The delivery of contents will also be based on cache servers close to the point of consumption. This solution can reduce the service-level latency by ensuring that the requested content is available from the local cache.

On the other hand, the advent of efficient transmission, detection, and decoding techniques for satellite communications has already helped to approach the theoretical transmission rates of a conventional point-to-point channel in which the interference is treated as noise. Within this framework, only incremental improvements in data transmission rates can be envisaged. As a consequence, physical layer network coding and interference alignment are now being considered as possible technical solutions for the interference issues.

**CONTEXT AWARENESS AND RECONFIGURABILITY**

In order to provide a flexible architecture supporting heterogeneous services, one of the main issues to be addressed is user-transparent network reconfigurability based on context-aware information. Context awareness is the ability to detect and estimate a system state or parameter, either global or concerning one of its components, in a radio system for enhancing performance at the physical, network, and application layers. Moreover, the awareness of the context can also indicate device features (capacity, resolution, etc.), users’ interests, places, and locations; the knowledge of this information can contribute to improving QoS and network utilization.

In the proposed future architecture, the possibility to establish the best connection to the Internet will be based on context awareness. Therefore, the services that will be afforded by the aforementioned techniques is a challenging research topic that may involve multi-sensor integration [10].

**INTERFERENCE MITIGATION AND ADAPTIVE STRATEGIES**

The scarcity of frequency spectrum and the ever growing demand for data throughput has increased attention to resource sharing and interference management in today’s satellite communication systems. In particular, the interference caused by spectrum sharing is deemed harmful, and its suppression by means of orthogonal transmissions in time, space, or frequency is not viable, especially in future heterogeneous systems. This is even more challenging if massive use of multispot antennas for the satellite forward link and cell densification are envisaged: these trends are likely to be adopted in the near future if the forecasts of traffic data growth in the coming years are confirmed.

In recent years, users of professional broadcast applications such as content contribution, distribution, and professional data services have requested more spectrum-efficient solutions. It is expected that in the near future the introduction of more efficient spectrum assignments and interference mitigation techniques in Ku- and wideband Ka-band transponders will become more and more crucial.
this radio access, such as heterogeneous content delivery, will be ideally provided anywhere on the planet.

Focusing on the end user side, the user shall be able to access the required service everywhere and independent of the available network resources. In the last few years the availability of heterogeneous network access technologies and new advanced multimedia services have led to the development of multiple network interface devices. Consequently, vertical handover among different technologies and smart routing mechanisms for dynamic interface management have been proposed. IEEE 802.21 is focused on handover and interoperability among heterogeneous networks, while the Multipath Transmission Control Protocol [12] addresses the simultaneous use of several interfaces aimed at increasing link bandwidth or always on connectivity. Cognitive algorithms, which allow the identification of the best network technology or path to reach the destination according to network parameters analysis, could be defined with the aim of increasing the provided QoS and therefore the QoE perceived by the end user. Moreover, the inclusion of the satellite as one of the interfaces that are available on the receiving device could be extremely useful in those areas where it represents the only network access technology (e.g., remote areas, critical contexts characterized by the unavailability of terrestrial infrastructure). New portable and handheld products have recently been launched in the market to address user mobility, such as Thuraya SatSleeve [13], which transforms a smartphone into a satellite smartphone, guaranteeing access in 161 countries across Thuraya’s coverage network.

SECURITY AND PRIVACY

The proposed context-aware service abstraction also provides unprecedented security issues that have to be carefully addressed. In the proposed framework, sensible information flows across paths that are characterized by different reliability grades; hence, weaker segments impact overall reliability and security. Current end-to-end cyphering technologies may be difficult to adopt when multi-homed connections are established between end users and a service cloud. A solution is the enforcement of privacy rules among trusted peers, the composition of which creates the complete service path. IPSec is a candidate for internal core segments for its scalability features and strong privacy provision. On radio access networks, physical layer security techniques like Noise-Loop [14] will efficiently provide the required privacy stratum allowing a secure key exchange mechanism with no a priori shared secrets. Biometrics [15] will also provide an easy and reliable identity verification mechanism to remote peers without the need for complex human-machine interactions.

ADOPTION OF SOCIAL NETWORKING CONCEPTS

Citizens may have important information about an event or an intervention scene, and by means of their mobile phones (with HD cameras and text messaging) may decide to share this information with others. Due to the availability of the advanced connectivity concepts and techniques that will be provided by future architectures, the adoption of social networking concepts within the network can be the basis for the introduction of applications allowing PSOs and citizens to share information efficiently (e.g., short messages) in rich formats (e.g., images) over a variety of devices. Hence, individuals may engage in content and social exchanges (e.g., request help, generate an alert) between self-formed groups. The applications will be context-, content-, social- and citizen-aware, and can be selected by end users according to their preferences and needs. As a result, the envisaged network and devices will need to meet the needs of the conception and creation of innovative end-user applications that support enhanced quality of life, mobility, security, and emergency activities.

NEW ECONOMICAL MODELS FOR INTEGRATED SYSTEMS

In the proposed context, the main benefits of using satellite technology as a complementary, alternative, or in some cases the only broadband access solution include technical, contractual, management, and deployment aspects. From the point of view of a service provider, considering the contractual issues, the possibility of contracting with a single operator over different sites, spread over a large area, allows many advantages to be achieved, decreasing the complexity of both deployment and management of services to devise a global system.

Moreover, focusing on the provisioning of new cost-effective commercial solutions and taking into account the flexibility of the proposed architecture, innovative satellite communication services should include bandwidth reservation systems based on pay-per-use services. The flexibility of the satellite bandwidth allocation as well as the possibility to hold down the network related costs enable the development of interesting commercial solutions. Different profiles can be defined according to the specific requirements of each service, and consequently a different charging and billing model can be applied. Charging can be either volume-based or time-based, enlarging the variety of services supported by this model. An example of a satellite bandwidth reservation mechanism integrated with e-health services is provided in [7].

CONCLUSION

Thanks to satellite segments, the integration of communication, positioning, and monitoring functionalities by means of heterogeneous networks will be enabled, allowing the definition of the future pervasive communication ecosystem. This fundamental step will permit the provision of a diversity of services and applications that will improve and enhance the quality of everyday life. In this article services related to the tele-health and security fields have been reviewed, and the future flexible proposed architecture is discussed. Finally, a detailed analysis of the open issues and trends to be taken into account is provided for the development of such architecture as well as of its single building blocks.
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BIOGRAPHIES

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