Wireless Pervasive Networks for Safety Operations and Secure Transportations

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***Abstract*— The paper contains an introduction about pervasive communications and networking and a focus about two application environments where wireless pervasive networks will be essential in future: information and communication technology (ICT) for emergency operations; and communication infrastructure for future logistics and secure transportation. Developing wireless pervasive networking for these environments imply the introduction of innovative solutions concerning: architectures, quality of service, mobility and security management, protocols, resource allocation, vertical handover, and delay tolerant networking. All these issues are discussed in the paper as well as the features of future interworking devices, called Interconnection Gateways, which may represent a suitable solution for efficient pervasive networking.**

***Index Terms*—Pervasive Networking, Delay Tolerant Networks, Networking Architectures, QoS Solutions.**

I. Introduction

THE paradigm of pervasive computing, also called ubiquitous computing, is a model of human-machine interaction where computing and processing power is totally integrated in everyday objects and activities [1]. These objects can also communicate with each other and with other components in order to form a pervasive/ubiquitous network. The idea, perfectly focused by [2], is sensing physical quantities, which presents a wide set of input modalities (vibrations, heat, light, pressure, magnetic fields,…), through sensors and transmit them through suitable seamless communication networks for information, decision, and control aim. Historically the concept of ubiquitous computing and networking was introduced by Mark Weiser and is contained in the paper [3] that envisages a world where sensors and digital information are integral part of people everyday life. The imagine that comes from that is the imagine of a person totally immersed within a telecommunication network who sends and receives digital information from the surrounding physical world and who interacts with it also unconsciously. Applications concern home applications and extend to all environments where monitoring and connecting physical world is important: civil protection, transportation, military, underwater, space monitoring and communications, among the others. As written in [2], "*We foresee thousands of devices embedded in the civil infrastructure (buildings, bridges, water ways, highways, and protected regions) to monitor structural health and detect crucial events*". Interdisciplinary advances are required to innovate in the field of pervasive computing and networking: new communication and networking solutions, new and less complex operating systems, miniaturized memorization capacity, innovative decision algorithms, efficient signal processing and context aware solutions. The aim is to create a pervasive network of devices which communicate data with each others and with other networking devices in seamless way. This objective imposes a meaningful change in the requirements that must be assured by the pervasive telecommunication infrastructure. In practice the aim is connecting anything, from anyplace, at anytime. These are the three keywords of the Internet of Things paradigm [4], born independently of pervasive networking but now strictly connected to it. From the viewpoint of telecommunications, the concepts of Pervasive Networks and Internet of Things are not distinguishable. Internet of Things refers to a network of objects to which an electronic identity and some active features have been given. Connecting the objects to each other and to other systems creates a pervasive network.

A pervasive network, so, is a telecommunication network composed of heterogeneous devices, differentiated for sizes, dynamics, and functions; and of heterogeneous communication solutions. Even if the integration of different device technologies, not necessarily IP-based (and, in this case, the correspondence between Pervasive Networking and Internet of Things is less obvious), is a topic of paramount importance, especially in emergency situations, the paper does not provide indications about it and focuses on networking aspects. So, different devices are connected through network portions that implement different technologies and protocols with the aim of creating a quality of service – guaranteed seemless end-to-end service. Additionally some communication links may be not available in some periods of time. In this case it would be recommendable that proper devices could store information up to connection availability. It means using the paradigm of Delay Tolerant Networks (DTNs). This feature is mandatory in interplanetary and underwater communications where intermittent links are a typical situation but may be very important also in other environments. So, a pervasive network not only is composed of heterogeneous devices and network portions but, sometimes, also by intermittent connectivity, large and variable delays, and high bit error rates. An idea is that the internetworking problems arising from a pervasive network

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may be tackled through proper Interconnection Gateways. These issues are highlighted in this paper through two application environments linked to safety operations and secure transportations.

The rest of the paper is organized as follows: sections II, and III are dedicated to the mentioned application environments. Section IV focuses on networking challenges in pervasive communications. Section V reports a possible innovative architecture based on Interworking Gateways. Section VI contains the conclusions.

II. ICT For Emergency Operations

Natural disaster events such as earthquakes, hurricanes, floods, and manmade ones such as terrorist attacks and toxic waste spills are facts of these last few years. Concerning only Europe, the European Community (EC) is dedicating a big attention to them. Not only the number of disaster occurrences is increasing very seriously but also the number of killed and severely injured people is dramatically high. Environmental impacts on human health and quality of life is very high and there is an increase in disaster risk.

Disaster events are often combined with the destruction of the local telecommunication infrastructure, if any. It implies real problems to the rescue operations. The quick deployment of a telecommunication infrastructure is essential for emergency and safety operations. The role of ICT is topical for the deployment of a telecommunication infrastructure for risk and emergency management.

The topic is very hot and many research groups are focusing on these issues. Just to mention few specific projects funded by the EC:

- For Public Safety Communication: Integration of early warning and all media alert systems (CHORIST); location based services, GSM, UMTS for search and rescue, TETRA for rescue team safety (STARRS); Ultrawide band communication for indoor positioning (EUPOPCOM); rapidly deployable communication systems for crisis management, Satcom plus WiMax, TETRA, UMTS (WISECOM, CHORIST); making the best use of existing infrastructure, IPv6 federating network, QoS (U2010).
- For Sensors Technology: General architecture SensorWeb (SANY); Advance self organising networks (WINSOC); Integration in-situ, UAV, HAP, mobile sensors (OSIRIS).
- For specific Sensor Applications: Forest fire (DYVINE), Water pollution (WARMER).

See [5-14] for detailed references. [15-18] are also worth mentioning.

All these projects are very ambitious and want to provide a real improved final service. So they tend to use commercial telecommunication infrastructures and to focus on their deployment more than on the many unsolved research issues linked to these types of pervasive networks, which could provide a great benefit at medium-long term.

Actually the reference telecommunication infrastructure that should be applied for emergencies would need to be quickly deployable, scalable, and reconfigurable. It must manage efficient interworking of heterogeneous portions and user mobility, have wide land coverage including isolated and hazardous areas, overcome geographical obstacles, and provide assured quality of service, possibly matching also intermittent links. In short it must have the main features of the pervasive networks described in the introduction. This type of network is necessarily composed of two main components: radio and satellite portions, possibly integrated by terrestrial networks, if available. All components such as sensors, vehicles and hand-devices can transmit voice and data and, so, be an information source. It is important to note that a telecommunication network for emergency is aimed at connecting different components and to convoy heterogeneous data such as voice, data, images (anything) over a heterogeneous network (anywhere) with time and quality of service constraints (anytime). All these aspects are hardly available in current commercial networking solutions.

Fig. 1 shows an example of pervasive communications aimed at transmitting critical data from and to hazardous areas within the framework of an emergency and monitoring operation. Sensors are mobile, small, non-intrusive pervasive computing nodes spread over the environment. Information from sensors is conveyed to a decision centre located by the headquarters. The availability of accurate and updated information is critical to both improve the responsiveness and accuracy of decisions, and the safety of personnel and devices on the field. Beyond the collected measures, a list of the information that can be conveyed by a pervasive architecture may include sensor position, physical and psychological fitness of the personnel of the organizations involved in the field, and data taken by operators, such as photos and videos. To get all these data from fixed and mobile devices and to transmit them to the headquarters, an efficient and secure data network, which is robust also against intermittent connectivity, is necessary. The scenario may dynamically change and the supporting heterogeneous network must be very flexible. Fixed terminals can be satellite and radio stations deployed in shelters, field hospitals, peacekeeping barracks and refugee camps. Satellite and radio mobile terminals may be hand held (e.g. radios and cell-phones), portable (small foldable sat terminal), vehicular (e.g. on car and trucks), and aeronautical (e.g. on planes and Unmanned Aerial Vehicles, UAV) devices. Terrestrial cable portions need to be integrated whenever available.

The described scenario includes United Nation (UN) peacekeeping forces in war zones, environmental monitoring, Governmental or Non-Governmental Organizations (GOs and NGOs), medical and humanitarian support in disaster areas and in critical regions.

A possible networking solution is represented by the use of Interconnection Gateways between the heterogeneous portions to guarantee seamless and quality of service based communication also in case of temporary link unavailability.

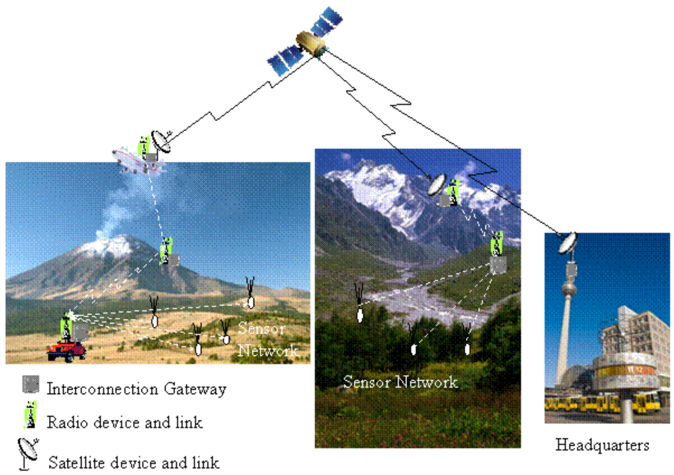

Fig. 1. Delay Tolerant Network (DTN) for communication in hazardous areas.

III. Communication Infrastructure for Future Logistics and Secure Transportation

Convergence between logistics and pervasive computing and networking is not only an interesting curiosity-driven research issue. Important investments in the industry have been oriented towards the integration of ICT and logistics. While, on one hand, many project are aimed at improving the transport chain: [19-25], among the others, some projects, on the other hand, are more focused on fostering the strategic alliance between ICT and logistics: [26-32].

The place where goods are assembled (e.g. in containers) may be: ports, airports, lorry and railway stations, and exchange areas. Goods are loaded over mobile means of transports such as ships, trains, lorries, and airplanes. Mobile means of transport and, possibly, single containers are geo-located through GPS/Galileo system. Goods, people, and monitored areas may be provided with sensors and/or video cameras/radios which can send information during the path from the starting to the destination point. The infrastructure includes also the presence of one or more centres of monitoring and control, located remotely to the goods/people path. These centres are aimed at tracking goods and at receiving information about their status. Possible practical applications are: dangerous goods tracking, transmission of documents for goods management, simultaneous software update in some/all means of transport or in single containers, multicast transmission of information reserved to means of transport joined by common features (for example, belonging to the same company, transporting the same goods, having the same destination, …). The examples evidence the need of a reliable and really pervasive network infrastructure that can adapt to the telecommunication system heterogeneity present along the path and that can support the monitoring service.

From the operative viewpoint, it means to study a novel telecommunication architecture that guarantees reliable and seamless information exchange about goods and surveillance people. The telecommunication infrastructure is highly heterogeneous. It contains sensor, wireless and satellite portions, connected to cable portions, if available. Technology-aware solutions should be investigated aimed at guaranteeing seamless connectivity and service transparency. Again the idea is using Interconnection Gateways, which know the access technology of network portions and can manage possible temporary link unavailability, as in the case of emergency networks. Additionally, in this case, different physical interfaces can be available to guarantee connectivity of anything, anytime and anywhere between monitored goods/people and centre for monitoring and control. So, Interconnection Gateways should also have a suitable structure to assure secure QoS-providing interworking as well as the best choice between heterogeneous access technologies. This last action is called vertical handover. The reference framework for vertical handover management can be the IEEE 802.21 standard and its evolutions.

Fig. 2 contains an example of heterogeneous network coverage and vertical handover onboard of a mobile mean of transport: satellite technology will provide coverage over fully maritime paths, but different technologies could provide coverage over port areas, exchange areas, and terrestrial paths. The ship in Fig. 2 contains a pervasive sensor network that transmits information to the Interconnection Gateway, which provides different interfaces both to communicate with sensors (but also with video cameras, and radios, if requested), via short-range interface, and to interconnect with backbones towards the centre for monitoring and control (long-range interface).

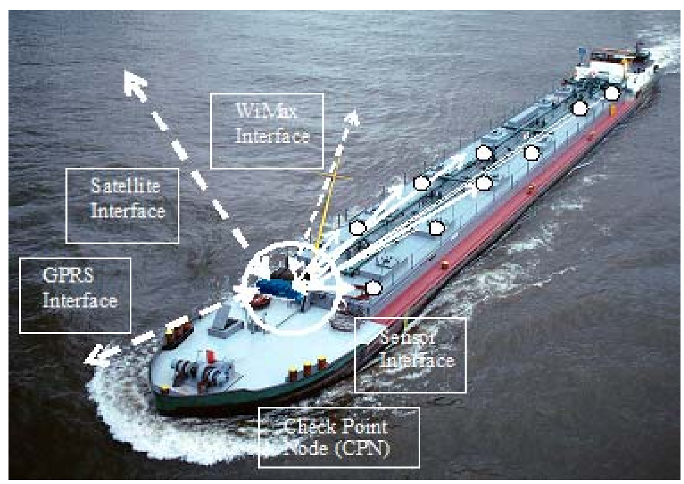

Fig. 2. Onboard pervasive telecommunication support.

IV. Pervasive Communication Networks: Networking Challenges

Today's Internet protocols are not particularly suited for heterogeneous environments, which need quick deployment and reconfiguration, mobility and security management, wide land coverage, quality of service provision, and long delay path and possible link disruption management. These environments are often referred to as Challenged Networks. Concerning long delay path and link disruption management, a possible solution is represented by the Delay-Tolerant Networking (DTN) Architecture, which "*embraces the concepts of occasionally-connected networks that may suffer* *from frequent partitions and that may be comprised of more than one divergent set of protocols or protocol families*" [33]. Even if originally thought for deep-space communications, DTN architecture is expected to be used in all operational environments to intermittent connectivity and high-delay. Other networks where DTN architecture can apply "*include sensor-based networks using scheduled intermittent connectivity, terrestrial wireless networks that cannot ordinarily maintain end-to-end connectivity, satellite networks with moderate delays and periodic connectivity, and underwater acoustic networks with moderate delays and frequent interruptions due to environmental factors.* [33]". DTN solution seems to be suitable for a wide variety of pervasive networks.

From the described scenarios and the aforementioned considerations, the scientific and technical challenges to match pervasive networking may be described as follows.

- Architectures – The heterogeneity of the pervasive networks introduces the need of proper architectures to manage the inter-working of satellite/wireless/cable network portions. A possible reference is represented by the Broadband Satellite Multimedia (BSM) architecture, developed by the European Telecommunications Standardization Institute (ETSI). It separates the layers identified as Satellite Dependent (SD) (data link and physical layer) from the ones identified as Satellite Independent (SI) (IP and upper layers). The interface between SI and SD layers is defined through SI-SAPs (Satellite Independent – Service Access Points), which should be located in the Interconnection Gateways. A possible action is to generalise the interface also for radio and cable interfaces so getting a common management of the lower layers interfaces. The new interface can be called TI-SAP (Technology Independent – Service Access Point), as done in [34]. Additionally new architectures should include long delay paths and link disruptions management. In this view, DTN architecture provides long-term storing and forward information switching to overcome communication disruptions. It provides a service similar to e-mail with enhanced routing and security features. It guarantees the storing of information in intermediate nodes until a communication link is available by implementing an additional layer, called Bundle Layer, located below the application layer. The design of this layer and of the convergence layer needed to implement it within real architectures is of topical importance.
- QoS Mapping – This issue is strongly linked to the architecture definition. The aim is to define a mapping between various QoS definitions and capabilities used in the different network portions. The mapping mechanism and implementation should give origin to a "seamless" communication. The mapping should be provided both "vertically" (i.e., the lower layers should offer a service to the upper layers) and "horizontally" (i.e., conforming the solutions used in different network portions through a proper signalling scheme).
- Protocols – Within the mentioned architecture, the design of specialised protocols is topical. Novel solutions may be applied at each protocol layer. Physical and data link layers are fundamental concerning the implementation of resource allocation schemes. The network layer has to efficiently use the bandwidth offered by the lower layers and implement QoS reservation and QoS mapping mechanisms. Transport and application protocols must efficiently use the services offered by the network layer. In this view, a cross-layer based approach is envisaged. The cross-layer definition allows a protocol entity to exploit the knowledge of a set of available parameters (measured or estimated) from the underlying layers and, hence, to provide an optimisation framework involving all the layers. New protocols should also include the mentioned DTN architecture.
- Resource Allocation – The aim is to find efficient and flexible allocation and reservation schemes, which also include congestion control and monitoring. As said, this topic is strictly connected with the implementation of physical and data link layers. The need to guarantee a specific Quality of Service (QoS) has implied the development of dynamic bandwidth allocation techniques, which take into account the current status of the channel. These works may represent a reference to design control schemes for heterogeneous networks. Nevertheless, heterogeneous networks including satellite and radio environments are characterised by several peculiarities, which require the introduction of suitable control strategies. Satellite and radio channels vary their characteristics depending on the weather and the effect of fading heavily affects the performance of the whole system and the quality perceived by the users.
- Vertical Handover – A network node (the Interconnection Gateway, in this case) may have multiple outgoing interfaces based on heterogeneous technologies such as satellite, WiFi, WiMax, LTE. The selection of the link on which to address information is very important because it impacts on the performance of the overall system. The dynamic choice should be based on the observation of physical parameters such as energy, channel and memory state, information loss and delay, possibly contrasting with each other. Actually choosing an interface that minimizes information loss can bring to a waste of energy and/or memory. Traditional single objective optimization techniques are not sufficient and other optimization concepts need to be studied and applied. A possible idea is using Multiple Attribute Decision Making – MADM Theory [35], as already done in other contexts [36]. MADM means "*making preference decisions (e.g., evaluation, prioritization, selection) over the available alternatives that are characterized by multiple, usually conflicting, attributes*" [35] and helps take the best compromise among the different choices.
- Mobility – It concerns the ability to support dynamic mobility (both micro and macro mobility), while keeping QoS definitions and reservations. This issue also refers to the need of having QoS aware routing protocols because routing, even during mobility, should take QoS constraints into account. The possible choice is linked also to the output interface for a specific packet, given the state of the buffers and of the channel. In this sense routing is strictly joined to vertical

handover management.

- Security – Security is a topic of paramount importance for heterogeneous interworking. It ranges from cryptography, to information coding, to secure network infrastructure. Its implementation involves all layers from physical to application. The topic would deserve a detailed discussion and an entire paper.

A possible idea is that the features mentioned above should be developed and implemented within Interconnection Gateways, whose design may also be object of a dedicated research project. A similar approach is already applied in EU projects [37] and [38]. The way to implementation is long and steep but some literature can help fix some basics. [34] has proposed a network node, called Quality of Service Relay Node (QoS-RN), which is a basic QoS Gateway and includes the essentials of the features mentioned above, except for DTN. QoS-RN should be located among networks (WANs – Wide Area Networks) that implement different technological solutions. Fig. 4 shows the architectural proposal reported in [34] to implement the QoS-RN between two WANs. The relay layer should include all the needed functions to match QoS mapping, resource allocation, protocol implementation, mobility, and secure interworking functions so assuring seamless communications. QoS-RN may be a good starting point for the implementation of Interconnection Gateways. A further step towards more complete QoS Gateways and towards Interconnection Gateways is to implement extended functions within the Relay Layer including transport and application layer enhancements such as PEPs (Performance Enhancing Proxies) functionalities. Fig. 5 shows the architecture: WAN2 in the middle deserves a dedicated special protocol stack to be optimized and the Relay Layer takes care of that. It means that the Relay Layer may implement, in case of need, two different protocol stacks: one towards WAN2 and one towards the external parts (WANs 1 and 3)..

Mobility and security management, which deserve a great deal of attention, are just mentioned in this paper. An important function is still missing: the DTN storing capability. A possible solution is given by the DTN architecture and by its Bundle Protocol (BP), clearly specified in [39] and [40]. Directly from [40]: "*Delay Tolerant Networking is an end-to-end architecture providing communications in and/or through highly stressed environments. Stressed networking environments include those with intermittent connectivity, large and/or variable delays, and high bit error rates. To provide its services, BP sits at the application layer of some number of constituent internets, forming a store-and-forward overlay network.*"

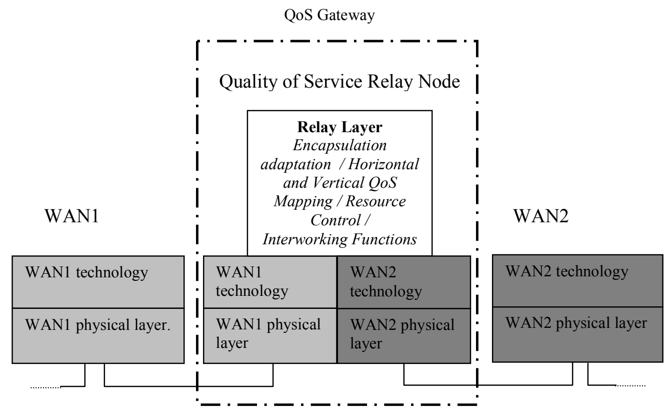

Fig. 4. Relay Node architecture.

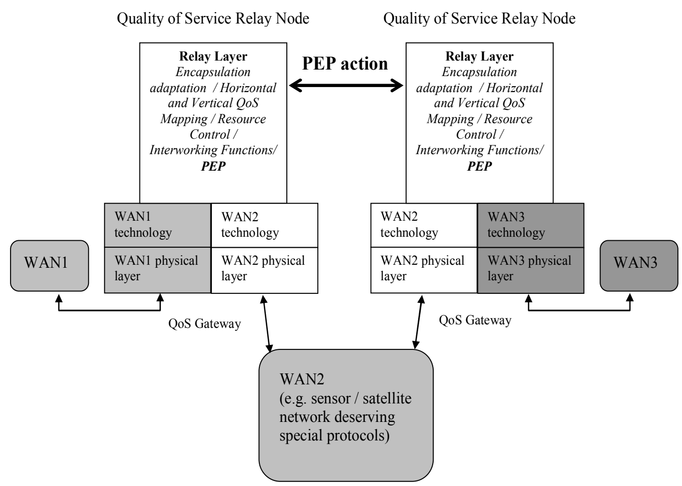

Fig. 5. Chain of Relay Nodes including PEP features.

Bundle Protocol can perform custody-based retransmission and can cope with intermittent connectivity. "*BP uses the "native" internet protocols for communications within a given internet. Note that "internet" in the preceding is used in a general sense and does not necessarily refer to TCP/IP. The interface between the common bundle protocol and a specific internetwork protocol suite is termed a "convergence layer adapter"*" [40]. The connection between two DTN Gateways that join different WANs is shown in Fig. 6.

The similarity of the architectures reported in Figs 6 and 5 is immediate. The difference stands in the capabilities. Only speaking about the transport layer action, a preliminary assessment of the disruption impact on the performance comparing PEP and DTN approaches is reported in [41].

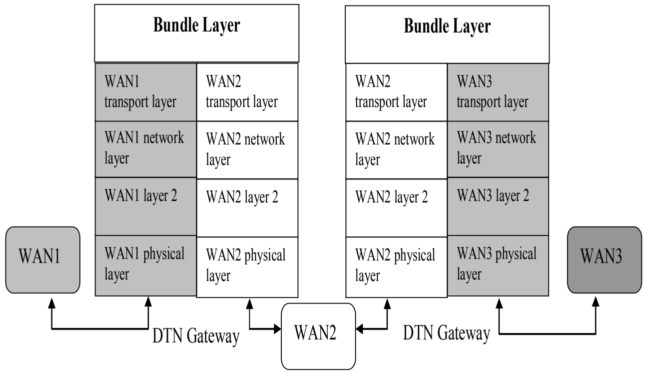

Fig. 6. DTN Gateways connection.

The original idea of this paper is merging the two architectures and going towards the implementation of Interconnection Gateways that have the quality of service capabilities of the QoS Gateways and the power of managing intermittent links as well as large and variable delays of the DTN Gateways.

V. Conclusions

The paper, through two challenging applications, focuses on the networking aspects of heterogeneous pervasive environments that have demanding deployment and reconfiguration needs, require efficient mobility and security management, act on wide land coverage, provide a given quality of service, and assure end-to-end data delivery also in case of very long delay path and temporary link disruption. Solutions at the state-of-the-art are not suitable for these communication environments. Innovative solutions concerning architectures and protocols are necessary.

This paper suggests using interworking devices called Interconnection Gateways which can join the functionalities of QoS Gateway such as QoS mapping, mobility and security management, and resource control, with the functionalities of DTN Gateways, which can efficiently manage temporary link unavailability and long delays.

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