# Extended Future Internet: An IP Pervasive Network Including Interplanetary Communication?

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**Abstract.** Starting from the evolution of Internet, this paper addresses the concept of pervasive computing whose aim is to create a pervasive network of heterogeneous devices which communicate data with each other and with other networking devices in a seamless way through heterogeneous network portions. This operative framework is also called Future Internet. Extending the idea of pervasive computing to interplanetary and other challenging links implies adding to the classical problems of pervasive communications such as quality of service, mobility and security, peculiarities such as intermittent connectivity, disruptive links, large and variable delays, and high bit error rates which are currently tackled through the paradigm of Delay and Disruption Tolerant Networking (DTNs). Satellite systems used to connect isolated and rural areas have already to cope with a series of challenges that are magnified in space communications characterized by huge distances among network nodes. At the same time, a space communication system must be reliable over time and the importance of enabling Internet-like communications with space vehicles (as well as with rural areas) is increasing, making the concept of extended Future Internet of practical importance. This paper will discuss this challenging issue.

**Keywords:** Internet · Pervasive communications · Future internet · Satellite communications · Delay and Disruption Tolerant Networking (DTN)

## 1 Introduction: Internet Evolution

The first step towards Future Internet is having a widespread diffusion of the Internet throughout the world. Table 1 reports the estimated population at the end of 2013 and the estimated number of Internet users at the end of 2013 and 2000 structured for world regions, showing also the world average. All data in this section are taken from [1].

Figure 1 shows the estimated Internet penetration rate (i.e. the percentage of estimated Internet users over the estimated population) in Dec. 2013 for each world region and for the world average. Penetration rate in North America is astonishing, and satisfying data are estimated for Europe and Oceania/Australia. Penetration rates in Middle East, Latin America/Caribbean, and, in particular, in Asia and Africa show that much work must still be done to fill the digital divide among world regions but, if, on


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one hand, this is a negative factor, on the other hand, the analysis of data evidences both the huge growth of Internet users in Asia, Middle East, Latin America/Caribbean, and Asia from 2000 to 2014, clear in Fig. 2, and the great potential of Asia, Africa, and Latin America/Caribbean due to the amount of population in these world regions. Figure 3, which shows the percentage of Internet users in the world distributed by world regions in Dec. 2013, may help evidence this last aspect: even if the estimated penetration rate in Asia is under 32 % for now, the number of estimated Internet users in this region is above 1.2 billions, which represent more than 45 % of the Internet users in the world. This fact, associated to an impressive growth of more than 1000 % in these last 13 years, allows envisaging a key role of Asia in Future Internet. Similar observations may be reported for Africa, which has a penetration rate of about 21 % but a 2000–2013 growth higher than 5200 % and a global population above 1 billion.

**Table 1.** Data about estimated population and estimated Internet users structured for world regions.

| World regions | Estimated population, Dec. 31, 2013 | Estimated internet users, Dec. 31, 2000 | Estimated internet users, Dec. 31, 2013 |
|---|---|---|---|
| Africa | 1,125,721,038.00 | 4,514,400.00 | 240,146,482.00 |
| Asia | 3,996,408,007.00 | 114,304,000.00 | 1,265,143,702.00 |
| Europe | 825,802,657.00 | 105,096,093.00 | 566,261,317.00 |
| Middle East | 231,062,860.00 | 3,284,800.00 | 103,829,614.00 |
| North America | 353,860,227.00 | 108,096,800.00 | 300,287,577.00 |
| Latin America/Caribbean | 612,279,181.00 | 18,068,919.00 | 302,006,016.00 |
| Oceania/Australia | 36,724,649.00 | 7,620,480.00 | 24,804,226.00 |
| WORLD TOTAL | 7,181,858,619.00 | 360,985,492.00 | 2,802,478,934.00 |

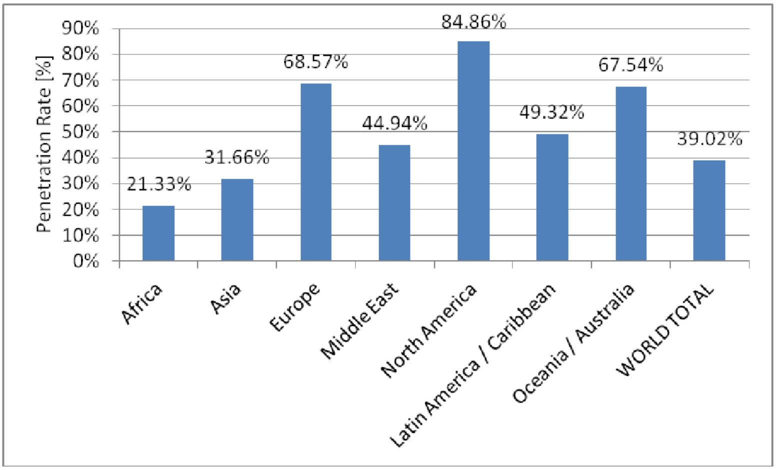


**Fig. 1.** Internet penetration rate, Dec. 31, 2013.

Concerning the mentioned digital divide, it has many complex motivations [2] including the following figures: temporal (having time to use digital media), material (possession and income), mental (technical ability and motivation), social (having a social network to assist in using digital media), and cultural (status and liking of being in the world of digital media), but one of the reasons is that a large amount of people lives in countries or in remote areas which do not have a suitable telecommunication infrastructure. The costs needed to connect these areas by using cables and common infrastructures are very high, in particular if compared with economic benefits. Satellite communications constitute a strategic sector for service provision in remote and low density population areas, as well as for aeronautical services, disaster prediction and relief, safety for critical users, search and rescue, data transmission for maritime environment, aviation and trains, and crisis management. The challenge is if satellite technology can fill the digital divide at service cost, reliability and quality comparable to terrestrial solutions. Actually, current satellite technologies require high costs in the construction, launch and maintenance, but nanosatellites [3] have been recently proposed as a cost-effective solution to extend the network access in rural and remote areas. Rural and/or disconnected areas can be connected through local gateways that will communicate with the nanosatellite constellation. The availability of the connection with nanosatellites is not permanently guaranteed and it deserves a dedicated solution, called DTN – Delay and Disruption Tolerant Networking, discussed in the remainder of the paper.

Given these data, is pervasive computing feasible? Next section provides more detail about this paradigm and about its evolution to Future Internet.

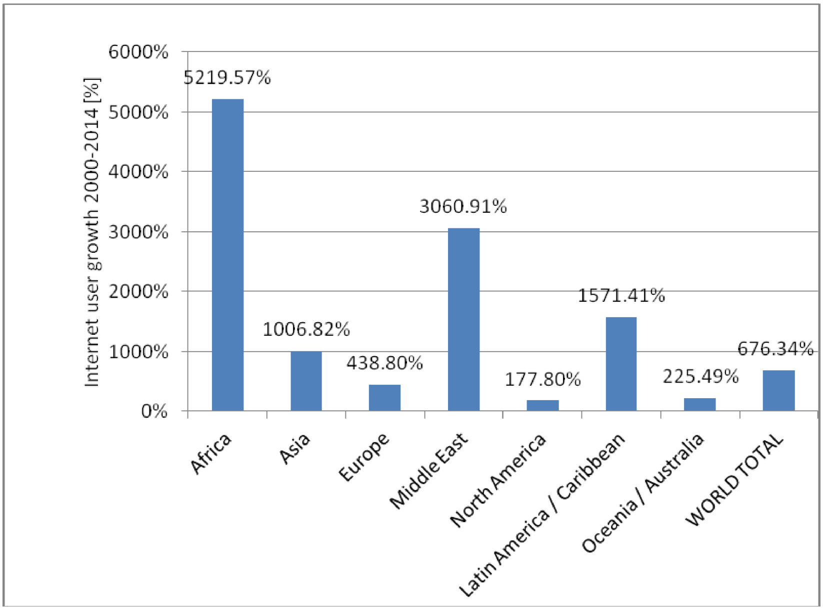


**Fig. 2.** Growth in the number of Internet users Dec. 31, 2000 – Dec. 31, 2013 (13 years).

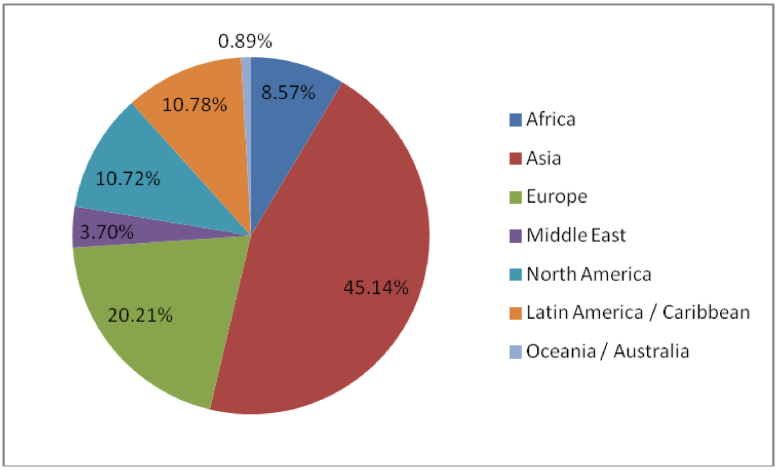


**Fig. 3.** Percentage of Internet users in the world distributed by world regions, Dec. 31, 2013.

## 2 From Pervasive Computing to Future Internet

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. These objects can also communicate with each other and with other components so forming a pervasive/ubiquitous communication network. The idea, perfectly focused by [4], is sensing physical quantities, which presents a wide set of input modalities (vibrations, heat, light, pressure, magnetic fields,…), through sensors and transmit them by using 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 [5] 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. The alarm clock asks about the will of drinking a coffee and activates the coffee machine in case of positive vocal answer; electronic trails reveal the presence of neighbours; evidencing some lines by a special pen in a newspaper it is sufficient to send these lines to your office for further elaboration. All these examples are taken from [5] but others may be created: the refrigerator gives indication about the status of the food; the washing machine and the heater may be switched on remotely; the car engine ignition may be switched on automatically when the owner is approaching, and so on. Obviously examples are not limited to home applications but 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 [4], “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”. Used embedded devices change their dimension depending on the application field. Three basic types are defined by Mark Weiser: Tabs that are wearable centimetre sized devices, Pads, which are hand-held decimetre-sized devices, and Boards, which are meter sized interactive display devices. In Weiser's vision all these devices are macro-sized, have a planar form and include visual output displays. Removing this requirements brings to new sets of devices for pervasive computing and networking whose dimension can be reduced down to millimetres, micrometers, and also nanometres (dust devices).

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 other 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 [6], born independently of pervasive networking but now strictly connected to it. At least 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 has been given an electronic identity and some active features. 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, ranging [7] from ADSL (Asymmetric Digital Subscriber Line) to DOCSIS (Data Over Cable Service Internet Specification); from fiber optic to PLC (Power Line Communication); from WiFi and its set of standards 802.11 dedicated to Wireless Local Area Networks – WLANs to WiMax, implemented through the 802.16 family, and LTE (Long Term Evolution), both suitable for the delivery of last mile wireless broadband access and to connect WiFi hotspots; from Bluetooth, acting over short ranges, to satellite solutions for planetary connections. Mentioned communication components not only implement different technologies but also often apply different protocols.

Figure 4 shows an example of pervasive network where there are many sensors that take physical measures and must transmit them remotely both to a mobile processing laboratory located on a plane and to a central laboratory located in a building (headquarters). In one case, data acquired from sensors are transmitted to a mobile station located on a off-road vehicle and, from there, to a satellite earth station through a wireless link. Data are broadcast through the satellite to an aeronautical network and, from there, forwarded to headquarters. In the other case data from sensors are directly received by a satellite earth station through a proper ad-hoc network and forwarded to headquarters via satellite.

Different network portions are connected by devices, called Interconnection Gateways in Fig. 4, whose role is to create a quality of service – guaranteed seemless interconnection of networks that implement different technologies and protocols.

Additionally some communication links may be not available in some periods of time. For example, observing Fig. 4, the link connectivity between the mobile station on the off-road vehicle and the satellite earth station may be intermittent because of the position of the vehicle; also the aeronautical link may be intermittent due to the plane position. In this case it would be recommendable that interconnection gateways could store information up to connection availability. This feature is mandatory in interplanetary and nanosatellite communications where intermittent links are a typical situation but may be very important also in other environments. Extending the idea of pervasive computing to interplanetary and other challenging links implies adding to the classical problems of pervasive communications such as quality of service, mobility and security, the peculiarities of interplanetary links such as intermittent connectivity, disruptive links, large and variable delays, and high bit error rates which are currently tackled through the paradigm of Delay and Disruption Tolerant Networking (DTNs). The idea is including within the pervasive IP network called Future Internet also interplanetary and challenging links, such as nanosatellites, connecting remote locations so creating an Extended Future Internet. An example is shown in Fig. 5. As in Fig. 4, some data measured remotely must be delivered to a data centre but, in this case, acquisition sensors are located on a remote planet and data centre on the Earth.

Satellite systems used to connect isolated and rural areas have to cope with a series of challenges such as long round trip times (RTTs); likelihood of data loss due to errors on the communication link; possible channel disruptions; and coverage issues at high latitudes and in challenging terrain. These problems are magnified in space communications characterized by huge distances among network nodes, extremely long delays, and intermittent connectivity. At the same time, a space communication system must be reliable over time, for example, due to the long duration of space missions, or due to the content of communications in rural areas. Moreover the importance of

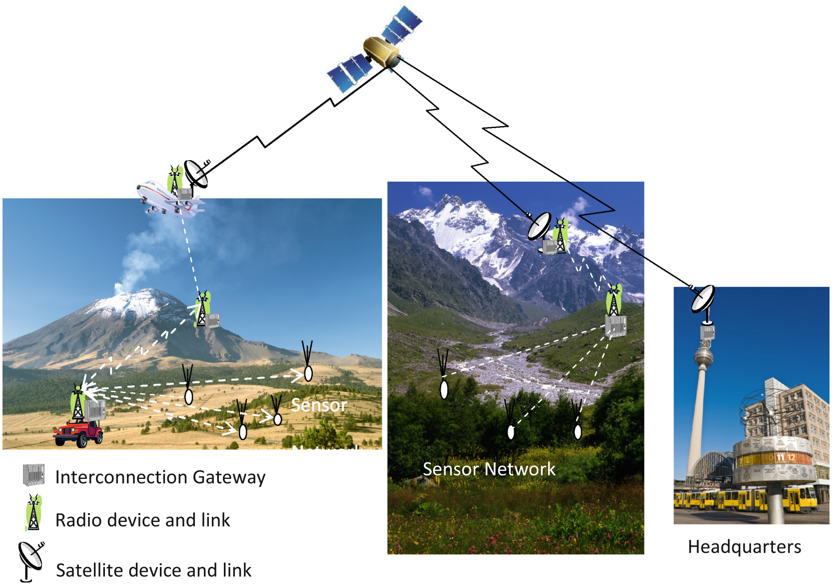


**Fig. 4.** Pervasive computing, example network.

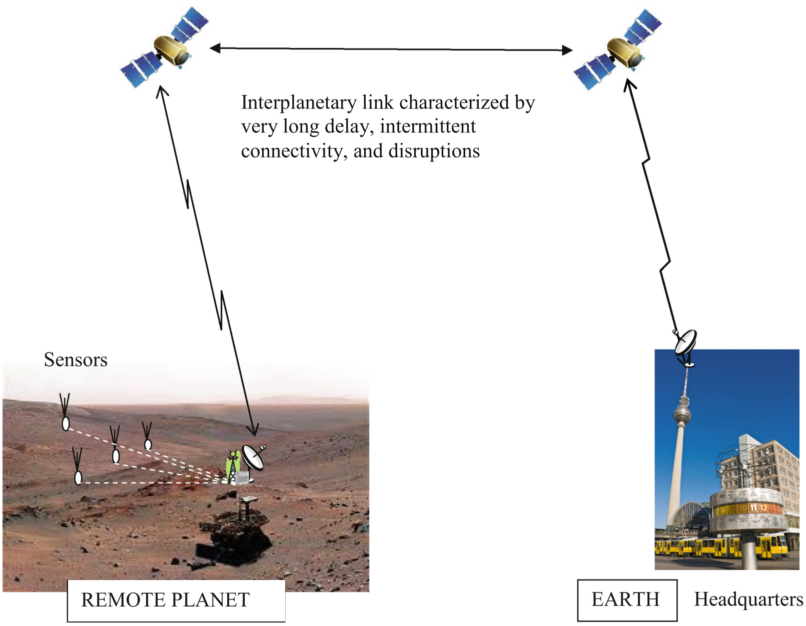


**Fig. 5.** Example of pervasive communication including long delay and intermittent connectivity.

enabling Internet-like communications with space vehicles as well as with rural areas is increasing, making the concept of extended Future Internet of practical importance.

## 3 Delay - and Disruption Tolerant Networking (DTN) and Its Application to Future Internet

The Delay and Disruption Tolerant Networking (DTN) architecture [8–11], introduces an overlay protocol that interfaces with either the transport layer or lower layers. Each node of the DTN architecture can store information for a long time before forwarding it. The origin of the DTN concept lies in a generalization of requirements identified for InterPlanetary Networking (IPN), where enormous latencies measured in tens of minutes, as well as limited and highly asymmetric bandwidth, must be faced. Nevertheless other scenarios, called “challenged networks”, such as military tactical networking, sparse sensor networks, and networking in developing or otherwise communications-challenged regions can benefit from the DTN solution. Nodes on the path can provide the storage necessary for data in transit before forwarding them to the next node on the path. The contemporaneous end-to-end connectivity that Transmission Control Protocol (TCP) and other transport protocols require in order to reliably transfer application data is not required. In practice, in standard TCP/IP networks, which assume continuous connectivity and short delays, routers perform non-persistent (short-term) storage and information is persistently stored only at end nodes. In DTN networks information is

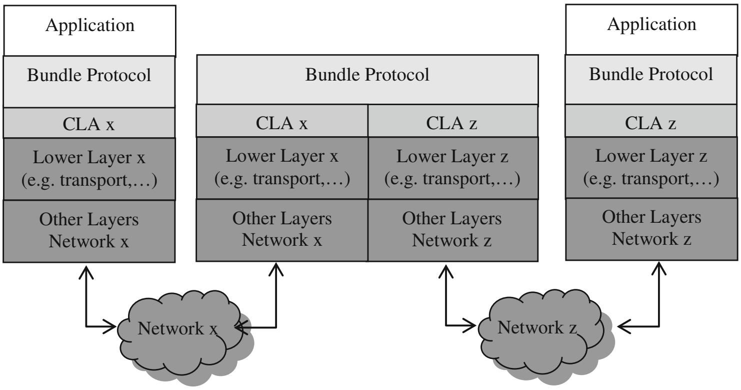


**Fig. 6.** DTN architecture.

persistently (long-term) stored at intermediate DTN nodes. This makes DTN much more robust against disruptions, disconnections, and node failures.

The Bundle Protocol (BP) is an implementation of the DTN architecture where the basic unit to transfer data is a Bundle, a message which carries application layer protocol data units, sender and destination names, and any additional data required for end-to-end delivery. The BP can interface with different lower layer protocols through convergence layer adapters (CLAs). CLAs for TCP, UDP, Licklider Transmission Protocol (LTP), Bluetooth, and raw Ethernet have been defined. Each DTN node can use the most suitable CLA to forward data. Generic DTN Architecture is shown in Fig. 6.

BP has important features such as: Custody Transfer, where an intermediate node can take custody of a bundle, relieving the original sender of the bundle which might never have the opportunity to retransmit the application data due to physical or power reasons; Proactive and Reactive Bundle Fragmentation, the former to tackle intermittent periodic connectivity when the amount of data that can be transferred is known a priori, the latter, which works ex post, when disruptions interrupt an ongoing bundle transfer; Late Binding, where, for example, when a bundle destination endpoint's identifier includes a Dynamic Name Server (DNS) name, only the CLA for the final DTN hop might have to resolve that DNS name to an IP address, while routing for earlier hops can be purely name based. Anyway, concerning the aim of this paper two are the BP features of main interest: (1) BP acts as an overlay layer and (2) can act as a long-term storage tool at intermediate nodes. These two features open the door to important applications of the DTN architecture, which:

- can be used as an alternative to PEP (Performance Enhancing Proxy) solutions,
- can be integrated within Interconnection Gateways that take care of quality of service – based internetworking among heterogeneous networks, as evidenced in the previous section,
- but can also store information and manage disruptions and long delays, if needed.

Generic idea is shown in Fig. 7.

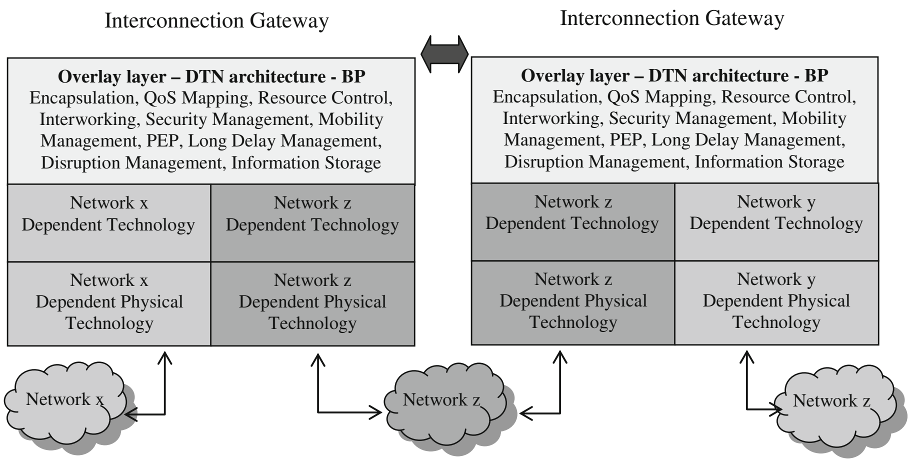


**Fig. 7.** DTN-based interconnection gateway.

## 4 Conclusions

This paper asks some basic questions: is pervasive communication extended to intermittent and disruptive links feasible and of practical interest or is it only an issue of academic investigation for now? To offer a possible answer the paper analyses the Internet evolution by showing the estimated number of Internet users at the end of 2013 structured for world regions and comparing these values with the same quantities at the end of 2000. Data concerning Asia and Africa show that much work must still be done to fill the digital divide among world regions but also show the huge growth of Internet users in Africa, Asia, Latin America/Caribbean, and Middle East from 2000 to 2014 and the great potential of these regions for the next future. This facts make the idea of connecting people and things from anyplace, at anytime, feasible. In the same time the importance of connecting rural areas, planets, and other remote locations characterized by intermittent and disruptive links makes the concept of Extended Future Internet a need. DTN offers a possible technical solution. So even if much research, in particular concerning modeling, routing, flow and congestion control, is still necessary to create a real Extended Future Internet, the challenge is worthwhile.

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