Global Communications Newsletter

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Terminodes: Self-Organized Mobile Ad-Hoc WANs

By Jean-Pierre Hubaux and Martin Vetterli, Switzerland

The Terminode Project is a 10-year research program (2000-2010) that investigates wide-area, large, totally wireless networks that we call mobile ad-hoc wide-area networks. This project follows a radically distributed approach in which all networking functions are embedded in the terminals themselves. Because they act as nodes and terminals at the same time, we call these devices terminodes. A terminode is a small personal communication device. A network of terminodes is an autonomous, self-organized network, completely independent of any infrastructure or other equipment. The project is led by the Swiss Federal Institute of Technology/Lausanne (EPFL). The sister institute in Zurich (ETHZ) is also heavily involved, along with several other universities. Prominent equipment manufacturers and network operators, as well as major relief organizations, have already joined this program or have expressed strong interest in its activities.

Research in multi-hop packet radio began in the 1970s. This area gained new momentum a few years ago under the keyword mobile ad-hoc networks. The IETF set up a working group devoted to it, called Mobile Ad-hoc NETworks (MANET, http://www.ietf.org/html.charters/manet-charter.html). For short-range communication, an industrial consortium standardized a low cost pico-cell wireless technology called Bluetooth (http://www.bluetooth.com/) in order to let various personal devices communicate with each other. For a wider range of transmission, Rooftop technology (http://www.rooftop.com/), based on an Internet radio architecture, enables communication among wireless Internet radios based on digital radio technology. Similar projects are being conducted in other Universities (http://www.dirc.net/home/index.html).

Our approach is different in several respects from the ones mentioned: our goal is totally self-organized wide-area networks, and we cover all layers (from the physical up to the applications).

Terminodes networks are our vision of a free, infrastructure-less network that covers a wide area. In this scenario, everyone could own a terminode in this area (city, region or country). The set of terminodes constitutes a large network where multi-hop wireless communications allow voice and data messaging between all the users. The whole network operates at unlicensed frequencies. It can be considered as a free, amateur, wide-area, wireless network. A terminode network can be any size. In particular, in regions of high-density population, the size could reach several million devices. In the following we summarize the main design points of the project.

The Spectrum is the Infrastructure: To eliminate the need for any additional device or network equipment, all networking functions (typically performed in backbone routers/switches and servers) are distributed in the terminodes. The only external resource needed by the users is the frequency bandwidth, normally allocated by regulation authorities.

Scalability to Large Numbers: Scalability to a very large number of terminodes is central to our research. In the Internet or in telecom networks, this issue is efficiently addressed using centralized and/or hierarchically organized routers and servers, which in the terminode context is inappropriate.

Decentralization and Self-organization: Terminodes are designed to be self-organizing: any number of terminodes that form a connected graph can constitute a network. Therefore, all terminodes have a common, minimal set of functions that are necessary and sufficient for the network's self-operation. Unlike in current networks, mechanisms that include centralized storage or processing must be substituted with completely distributed solutions.

CB Business Model: The terminodes introduce an original business scenario in multimedia communication services. In today's networks, most multimedia communication services, including those supported by the Internet, are seen by the end user as commercial services that include a service contract and regular fees. In the scenario we consider, the paradigm is radically changed: terminodes are goods that people purchase once and use forever, without service contracts or per-use-basis fees. This is similar to citizen band, amateur radio and walkie-talkie equipment.

The network we envision is based on connection-less packet switching. An end-system unique identifier (EUI), typically coded on 64 bits, will identify each terminode. In addition, each terminode will have a temporary, location-dependent address (LDA). The LDA is a triplet of geographic coordinates (longitude, latitude, elevation), obtained by means of the geographic positioning system (GPS), for example. Since terminodes have to relay packets, the intermediate system functions should be as simple as possible. For this reason, terminodes do not contain any routing tables or algorithms. Their relaying function simply consists of relaying the received packets to the "best" appropriate neighbor, based on the ultimate destination of the packet and on some global knowledge the terminode has about connectivity of the network and possible congestions.

The identification of the best neighbor, and mechanisms to realize "long hops" to reach distant nodes, are currently under investigation. As for the integration with the Internet, we will request a reservation of a portion of the IPv6 addressing space for terminodes; the IPv6 address of a terminode is then algorithmically mapped from its EUI. From an IPv6 viewpoint, the set of terminodes is one enormous subnetwork. Two terminodes typically use the TCP/IP protocol stack to communicate. However, inside the network of terminodes,

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Wireless Demand in America

By Carlos Hirsch, Mexico

There are two telecom services that are growing faster and at higher rates than anybody could imagine a few years ago. Of course, we are talking about wireless and the Internet. I will not try to explain this phenomenon, it is something out of my scope, but we all celebrate this success. The purpose of this analysis is to give an understanding of the demand for wireless services in America, from an engineering and economic point of view.

Let's start by thinking about the main differences between wireless and wireline. For wireline access, more than 50 percent of the total investment is dedicated to a single customer, from the switch port to the home outlet. Whether used or not, this investment must be depreciated, maintained, upgraded and made profitable. That is why we measure wireline networks based on main lines. Most of the wireline cost is related to the number of lines in service and the costs related to local traffic are minimal, much less than US 1 cent per minute. This variable cost is usually used as a reference to calculate interconnection rates between carriers.

Turning our attention to wireless, most investments depend on coverage and installed airtime capacity. In contrast to wireline, the investment is for a shared infrastructure. That means that most costs are traffic related and customer-specific costs are minimal, such as occasional regulatory costs on a per customer or per number basis. The market value of wireless companies is still measured by number of customers, but I believe a more appropriate measure is air-time usage, and I am convinced that this change in measurement will occur very soon.

To continue, let's analyze the key drivers pushing wireless demand in America. The simplest way to compare relative telecom development between countries is teledensity. Considering only these figures could be misleading because we are neglecting the country's demand and wealth. Table 1 lists several American countries in order of cellular teledensity (cellular customers per 100 inhabitants). Another valuable measure to consider is customers per GDP. There is a different picture!

The last column indicates the year of calling party pays (CPP) introduction. It is the main driver to explain these numbers, but not the only one. Of course, how long cellular has been in service, prepaid systems and the regulatory and competitive environment are needed to explain the whole story.

Country	Cellular teledensity	Cellular/GDP	CPP
US	33	11	NO
Canada	23	11	NO
Venezuela	11	25	1993
Argentina	11	15	1997
Chile	9	21	1999
Mexico	8	15	1999
Brazil	8	25	1994
Peru	5	21	1996
Uruguay	5	8	1995
El Salvador	5	29	NO
Colombia	4	25	1994
Costa Rica	4	12	1997
Honduras	1	12	NO

Table 1. *Cellular teledensity in 1999, same figure related to GDP and CPP availability.*

The second question we address is related to usage. If we look at minutes of use (MOU) per customer, they are decreasing each year for all countries. Numbers started at 300 minutes per month per customer 10 years ago; today it is approximately 100 minutes in most countries. We have not experienced a similar decreasing usage per user in wireline networks despite having changed teledensity in similar proportions. There is no evidence of new wireline users talking less than older customers.

It is obvious that the key driver for usage is price elasticity. For telecom service there are two components of price: FMC, the fixed monthly charge (the monthly fee and the handset cost over 24 months), and PPM, the price per minute (usage dependent).

Based on eight years Mexican data we obtained an equation for usage:

$$MOU = a * GDPpercapita^{b} * \gamma^{c}$$

where γ = FMC/PPM, a = 0.001, b = 1.2, and c = 0.35

The fixed part of γ is mainly the handset cost and has decreased very sharply based on Moore's Law as well as the fact that there is almost no cost per customer in wireless networks. On the other hand, average price per minute is technology-dependent and has been fairly constant over time, even though in cases like prepaid, which is driven by marketing costs, it has become more expensive. In wireline networks, γ remained fairly constant over time based on cross subsidies.

As a final comment, new data services could increase usage, similar to what we are experiencing with the Internet. However, the opposite trend exists as well as more intelligent devices connected to the network will drive usage downward.

A Report on COMCON7

By Voula Georgopoulos, Greece

The 7th International Conference on Communications and Control (COMCON7) was held in Athens, Greece from June 28 to July 2 1999 at the Astir Palace Hotel. The focus of the conference was telecommunications and signal processing. This international conference is held every other year and has been held in different places in Greece since 1993. The conference included sessions on antennas/EM, ATM, cellular and wireless, networks, devices, medical applications, signal processing, chaotic communications, RF transmission, stochastics and control. The main sponsor of the conference was the Hellenic Telecommunications Organization (OTE); other sponsors included Intracom and Siemens Hellas. The organizing committee consisted of A. V. Balakrishnan (Chairman) and N. Levan from UCLA, E. Billis from OTE, and W. Wells from the University of Nevada Las Vegas. The International Program Committee was led by A. Viterbi (Chairman) and included members from the United States, Canada, Italy, and Greece. The conference had participants from academic, governmental and industrial institutions from 18 countries in Europe, Asia and North America.

There were three plenary sessions which included discussions on the challenges that lay ahead in areas such as mobile computing, Internet communications, Web-based teaching and remote classrooms, Internet commerce, multimedia technology, telecommunications applications in human health, information society technologies, and 3G base stations. The total number of papers exceeded 110 and were published in the Conference Proceedings.

Report from the St. Petersburg Chapter

By Dmitry Tkachenko, Russia

A number of new members of the IEEE Communications Society (ComSoc) were recruited by the St. Petersburg Broadcast Technology Society (BTS) Chapter for the year 1999, in response to the demand for local activity in the field of communications. As a result, the status of the Chapter was changed from a single BTS Chapter a to joint BTS/ComSoc Chapter in the beginning of 1999. The Chapter immediately started intensive activity in the field in collaboration with other international and Russian organizations. Among 1999 activities of the Chapter we will mention the following:

• The first international conference on Advances and Future Development of Cable and Satellite Television, was held in the framework of the exhibition Cable & Satellite Russia – 99 (Moscow, Exhibition Center Sokolniki, 24-27 February 1999). About 40 papers were presented at the conference and about 500 specialists attended.

• The first seminar on Advanced Systems of Mobile Communications was held in St. Petersburg on 18 February 1999 in the framework of the NORWECOM '99 exhibition (the largest annual exhibition on communications in northwest Russia). Twelve papers were presented at the seminar and about 100 specialists attended.

• The first conference on Advances in Television, Audio and Video Technologies was held in St. Petersburg at the exhibition center Lenexpo on 24-25 June 1999. At this conference 24 papers were presented and approximately 150 specialists attended.

• A grant from the Communications Society was received by the Chapter to attend the First IEEE/Popov Workshop on Internet Technologies and Services (25-28 October, 1999, Moscow). Several members of the Chapter attended the workshop and made presentations.

• On 27 October, active members of the Chapter took part in the administrative meeting with IEEE ComSoc President Thomas Plevyak and the management of the IEEE Russia Section and Russian Popov Society. Possible fields of further collaboration were considered and the Sister Society Agreement between IEEE ComSoc and the Popov Society was discussed and signed at the meeting.

• The Chapter played an active role in the preparation of the Russian Section of ICC '2001 (International Conference on Communications) that will be held in St. Petersburg on 11-15 June, 2001, and will be connected with the main conference in Helsinki by means of videoconferencing. The Organizing Committee and Program Committee for the event were established and, on 4 November, a meeting with ICC '2001 General Chair Kaj Linden and his colleagues was organized at St. Petersburg Electrotechnical University. Coordination of efforts from both sides and further activity on preparing the event were discussed at the meeting.

In 2000, the Chapter is planning the following activities in cooperation with other organizations:

• The Second International Conference on Cable and

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The First IEEE Conference on Standardization and Innovation in Information Technology

By Kai Jakobs, Germany

Considering the overriding importance of high-quality standards for a society that increasingly relies on interconnected and interoperating IT devices, public events on any of the various aspects related to standards and standardization are surprisingly few. Against this background, the first IEEE Conference on Standardization and Innovation in Information Technology (SIIT '99) was organized to bring together researchers and practitioners from the (normally separated) disciplines of telecommunications, technology studies, economics, business studies, management sciences, politics, and computer science, as well as IT users. If the participants' comments are any indication, this goal was achieved.

The conference was held in Aachen, Germany, on September 15-17, 1999. The number of participants was approximately 70, from 23 countries on four continents.

A number of distinguished experts had been invited. Very much in line with the idea of the conference, their talks covered a wide variety of topics:

• Christine Schatzl (European Commission) presented "The Role of Standards in the Information Society."

• Gary Robinson, an independent standards consultant, argued that "There are no Standards for Making Standards."

• Robin Williams (Edinburgh U.) discussed "ICT Standard Setting from an Innovation Studies Perspective."

• Fabio Bigi (ITU) described the "ITU-T Studies in GII."

• Helmut Schink (ETSI) talked about "Standardization: Welcome to the Market Place."

The session program included 20 oral presentations covering such diverse yet related issues as "Organizational Aspects of Standardization," "The Standards Setting Process," "On Innovation," "Economic Issues and Theory of Standardization," and "Specific Standards and Applications." A poster session covered "The Many Facets of Standardization."

These rather more 'traditional' sessions were complemented by three more-interactive sessions:

• "Standards Strategies in the Commercial World" were explored by two panelists who are very familiar with them: Carl Cargill (SUN) and Stephen Walli (Microsoft).

• Trying to look into the future, panelists representing the major stakeholders of the standards-setting process were assembled to discuss "Standardization in the Next Millennium: Where Do We Go from Here?" These included Koichi Asatani (ITU) for the "traditional" standards bodies, James Boyd (ISSS) for the "new" bodies, Helmut Schink (Siemens) representing the vendors, Pierre-André Probst (Swisscom) as a service provider, Christine Schatzl (European Commission) for the regulators, and Ewan Sutherland (INTUG) as the user representative.

• Tineke Egyedi (Delft U.) and Eric Monteiro (NTNU) had a public debate on whether there is a future for the Internet's standardization process, from a technology studies perspective.

Finally, a special workshop was dedicated to the presentation and discussion of "Electronic Tools to Support Standardization Work."

Aachen, a not-too-big town near the Dutch and Belgian borders, is a place steeped in history. It is probably best

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ST. PETERSBURG CHAPTER/*(Continued from page 3)*

Satellite Television of the XXI Century will be held in the framework of the exhibition Cable & Satellite Russia – 2000 (Moscow, Exhibition Center Sokolniki, 16-18 February, 2000). Among other organizers of the Conference are the Ministry of the Russian Federation on Communications and Informatization, the Ministry of the Russian Federation on Press, TV, Radio Broadcasting and Means of Mass Communications, the Russia Section of the Institute of Electrical and Electronics Engineers (IEEE), the Advanced Television Systems Committee (ATSC), the DigiTAG Action Group associated with the European Broadcasting Union (EBU) and DVB Consortium, the State Radio Research & Development Institute, the Russian Research Institute for TV and Radio Broadcasting, and a number of other leading Russian organizations.

• The international workshop on Perspectives for Implementation of VSAT Technologies will also be held in the framework of the conference and exhibition Cable & Satellite Russia – 2000 on 17 February, 2000, in cooperation with the Global VSAT Forum and the Russian National Assembly of Satellite Communication.

• The second seminar on Advanced Systems of Mobile Communications will be held in St. Petersburg in the framework of the exhibition NORWECOM – 2000 (15-19 February, 2000).

• The second conference on Advances in Television, Audio and Video Technologies, to be held in St. Petersburg in May, 2000, is now under consideration.

• The workshop on Mobile Communications, to be held in St. Petersburg in June, 2000, is now under consideration.

More detailed information on these events may be received from the Chapter chairman, Dr. Dmitry Tkachenko, at ppdtkach@dux.ru

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TERMINODES/*(Continued from page 1)*

packet forwarding does not utilize IP addresses, just as bridges operate in a large bridged network.

The radio system of terminodes presents unique challenges. We are currently studying the appropriateness and performance of spread-spectrum techniques. Of note, research questions address power control, distributed allocation of codes, and a possible organization of terminodes in radio clusters.

Mobility management also requires particular attention. Paging a terminode cannot be achieved by flooding the network, as this mechanism would not scale. Moreover, we cannot rely on centralized servers as cellular networks do, because we do not have any infrastructure. For these reasons, mobility management of terminodes is based on an original approach that we have named the virtual home region (VHR). A VHR is a set of terminodes, located near each other, that store the current location of a given terminode. According to this principle, each terminode has an associated VHR. A hash-function makes it possible to associate a given EUI with the geographic location of its VHR in a known way.

Since terminodes are mobile, another area of concern is security. Their interactions are spontaneous and unpredictable, which makes public key cryptography more appropriate. Key management is clearly a major challenge in a self-organized network, because there are no certification authorities. One solution we are currently investigating is to base the trust on a community of users, as is the case in PGP (Pretty Good Privacy).

Finally, the incentive to collaborate is also an important issue. There must be a mechanism that encourages users to behave as "good citizens" by letting their device relay packets for the benefit of other users. One possible approach to stimulate such behavior is to introduce the concept of service charges. The basic idea is that terminodes that used a service should be charged and terminodes that provided a service should be remunerated.

Terminodes can be useful in a number of scenarios. First, they can play a very important role in the case of natural disasters. An earthquake, hurricane, or flood can severely damage the wired and wireless infrastructure of a region. At the same time, the need to communicate increases dramatically. Terminodes can be a way to keep communication operational.

A second example is related to political instability. Too often, the communication network of a given region does not have the appropriate level of dependability. By empowering citizens with the networking functions, the terminodes can allow people to stay connected even in very adverse circumstances.

Finally, terminodes can support a kind of "citizen band." Recently, prominent car manufacturers have expressed very aggressive plans for the provision of terminode-like devices on each car. In this way, the network could be used to exchange information about traffic conditions, or even to establish voice communication independently of any fixed infrastructure.

For more information, see http://www.terminodes.org

REPORT ON SIIT '99/*(Continued from page 3)*

known for the coronation of Charlemagne, its cathedral (a UNESCO World Heritage Site), and its annual horse show, CHIO. Once more calling upon the participants, it was an excellent venue, and one which should apparently be used more often. Yet, the successor conference will be held in Boulder, Colorado, in March 2001.

The conference was co-sponsored by the European Commission, DGIII; the IEEE Communications Society; the Technical University of Aachen; and AixCom e.V.