The Terminode Project: Towards Mobile Ad-Hoc WANs

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Abstract— **The Terminode project follows a system approach to investigate wide area, large, totally wireless networks that we call** *mobile ad-hoc wide area networks*. **A network of terminodes is an autonomous, self-organized, wireless multimedia network, independent of any infrastructure. In this paper we present the main challenges and certain initial technical directions.**

I. Introduction

The Terminode project is a long term Swiss project [1] that follows a system approach to investigate wide area, large, totally wireless networks that we call *mobile ad-hoc wide area networks*. In this project, we follow a radically distributed approach in which all networking functions are embedded in the terminals themselves [2]. Because they act as nodes and terminals at the same time, we call these devices *terminodes*. A network of terminodes is an autonomous, self-operated network, completely independent of any infrastructure or other equipment.

II. The Vision

Our vision of the Terminode project can be illustrated by a scenario of a free wireless network covering a wide area. In this scenario terminodes are small personal devices potentially owned by everybody in a wide 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 users. The whole network operates at unlicensed frequencies. It can be considered as a free amateur wide area wireless network. Terminode users can be human or equipment, depending on the application. 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 users is the frequency bandwidth, assumed to be allocated by regulation authorities. The fact that routing/switching functions are performed in the terminodes dramatically changes the routing paradigm. A backbone of routers or switches typically looks like a tree, sometime augmented with few redundant links. In the terminode approach, the backbone is identical to the set of terminodes and looks more like a strongly connected graph with a very high level of redundancy.

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

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 self-operation (*peer-to-peer* [3]). Compared to current networks, mechanisms that include centralized storage or processing must be substituted with completely distributed solutions. However, this does not imply that all terminodes are identical. A terminode can be individually extended with large processing, storage or internetworking capabilities that could benefit the entire community of terminodes – under the condition that these extensions are not necessary to run the network.

CB Business Model: The terminodes introduce an original business scenario in multimedia communication services. In today's networks, most multimedia communication services, including the ones 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 talkie-walkie equipment.

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III. Related Work

TABLE I
Historical Overview

Year	Technology	Organization
mid 1980s	AMPS	ATT
1993	DECT	ETSI
1993	GSM/DCS1800	ETSI
mid 1990s	IS-136	TIA
1997	UMTS/IMT2000	ETSI/ITU-T
1998	IS-95	Qualcom
2000+	Teledesic	Teledesic
1970	Packet Radio	DARPA
mid 1990s	802.11	IEEE
mid 1990s	HIPERLAN-1	ETSI
1997	Adhoc Networks	IETF MANET
1998	Bluetooth	Bluetooth SIG
1999	802.15	IEEE
1999	802.16	IEEE

Research in mobile ad-hoc networks was initiated in DARPA Packet Radio projects [4]. Subsequently, research communities worked on projects that address mainly medium access control and routing issues. In the last few years, projects such as Monarch , Wins, etc.. (see [1]) produced several routing protocols, simulation tools, simulation analysis, and performed trials. Then, mobile ad-hoc networks became accepted as valid commercial concepts, as confirmed by the creation of the MANET working group in IETF [5]. Past work has focused on small networks. Based on the existing routing protocols, significant effort is currently being made in order to achieve scalability [6],[7],[8],[9]. Rather than following an evolutionary approach, we decided to investigate a different type of routing based on the physical location of the destination. A similar idea is used in [10], [12], [11], but we combine it with new location and packet forwarding algorithms, designed specifically for networks with several million nodes. The MAC layer specified in the IEEE 802.11 standard is usually used in current ad-hoc network projects. The standard uses a Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) scheme based on short channel allocation messages. This technology is already used in wireless LANs. More recently, the Bluetooth standard has been defined as a low cost pico-cell wireless technology suitable for purposes such as cable replacement. However, it is still unclear how profitable it can be to mobile ad-hoc networks.

IV. Technical Directions

In this section we outline the main technical challenges posed by the design of a self-organizing, very large, mobile network, and we sketch some initial technical directions.

A. Packet Switching and Burnt-In Addresses

We envision a terminode network based on packet switching. While circuit switching is an advantage for supporting voice (very small delay in relaying terminodes), the complexity associated with establishing, maintaining, and releasing circuits, or any form of connection, is probably at odds with the requirement that intermediate systems are user equipment, and may operate quite irregularly. Thus, we use connection-less packet switching. Delay will be minimized by supporting cut-through operations: routing information is placed at the beginning of the packet header and forwarding starts as soon as valid routing information has been analyzed.

Terminodes must be identified by some means of addressing. We need an address that a terminode can use without configuration; every terminode has a burnt-in 64 bit End-system Unique Identifier (EUI), as is planned today in the replacement of MAC addresses for any communication equipment. Note that terminodes are able to work with the Internet protocol (see below), however it is not a good idea to use IP addresses as unique identifiers because, as long as IPv6 is not really deployed, there are not enough IPv4 addresses that could be set aside for the exclusive use of terminodes.

B. Radio Resources Allocation and Automatic Scalability

Terminodes use one, or several, non-operated frequency bands assumed to be allocated for that purpose. It is not clear which technology is best adapted, and this will be an object of research; today we can assume that code division multiplexing is used. A terminode establishes direct radio connections with a small number of other terminodes (“friends”); a terminode and its friends agree on the code they use; a broadcast channel is used for verifying that a code can be used. Friends may be close neighbors, and when terminodes also have remote friends, there would be obvious advantages for the network.

In a dense area, terminodes tend to have many of their friends in close vicinity, and thus send with low power; this guarantees that the radio resource can be re-used, and thus lets the network throughput automatically scale with its density. The exact protocol

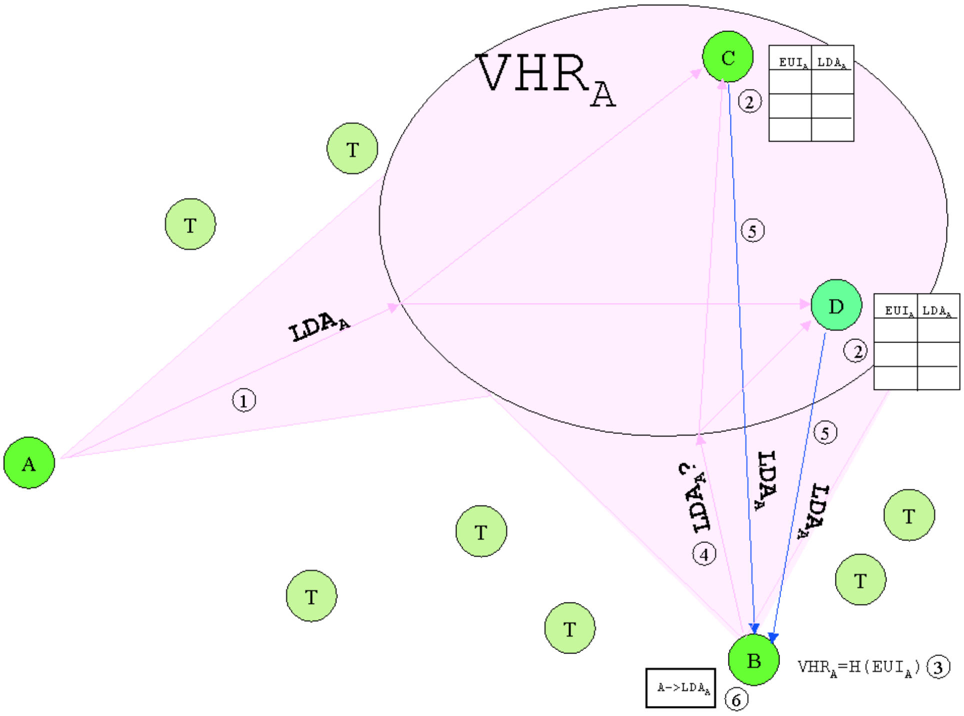

Fig. 1. Overview of the operations in the location algorithm. The terminode A sends (1) its position (LDA_A) to its virtual home region (VHR_A, that contains C and D). The terminodes C and D store (2) the mapping between EUI_A and LDA_A. The terminode B can thus request (4) the LDA_A to the nodes in the VHR_A that it computes (3) as $VHR_A = H(EUI_A)$. C and D send (5) this information to B. B stores (6) this information in its table.

used on the broadcast channel for establishing friendships is not yet designed.

C. Geodesic Packet Forwarding, GPS and Location Algorithm

Since relaying functions are performed by terminodes themselves, the intermediate system functions should be as simple as possible, as is the case, for example, with source routing bridges. In a large, self-operated network, it may not be feasible to use routing protocols, which distribute in one way or another some knowledge about the topology of the network. In contrast, we propose to use a combination of *local* and *geodesic* packet forwarding, described below. To this end, every terminode has, in addition to its permanent EUI, a temporary, location-dependent address (LDA). The LDA is simply a triple of geographic coordinates (longitude, latitude, altitude), obtained for example by means of the geographic positioning system (GPS)[1].

Packet forwarding works as follows. As destination addresses, packets contain both the EUI and an estimate of the LDA of the destination. A terminode keeps the EUIs and LDAs of all current friends; when it receives a packet, it checks whether the destination EUI is in the list of friends, and if so, sends it to the destination (local packet forwarding). Otherwise, it looks at the destination LDA and computes an estimate of which friend is closer to the destination, from a geographical viewpoint (geodesic packet forwarding); then it sends the packet to that friend. Looping packets are discarded by the beans mechanism described below (similar to the TTL field in IP packets). Convergence of the scheme requires some properties of the distribution of friends. A detailed modeling and analysis is object of our research.

With this scheme, a terminode must have an indication of the LDA for all communication partners. This is performed with the *location* algorithm. Here we cannot rely on any permanent database; instead, every EUI is associated (by means of a hash function) to an area of geographical coordinates (virtual home region, VHR). The VHR is defined by a triple of geographical coordinates and a default radius. A terminode, say A, periodically sends towards its VHR position advertisements; these advertisements are forwarded with the geodesic method. All terminodes in the A's VHR store the mapping between the A's EUI and its LDA, and acknowledge this to A. The radius

[1] Coding longitude and latitude with an accuracy of 10^{-4} grades gives a position accuracy of about 10 meters. With this accuracy, the total number of position triples is to the order of 10^{16}, thus an LDA could be coded with 48 bits, approximately.

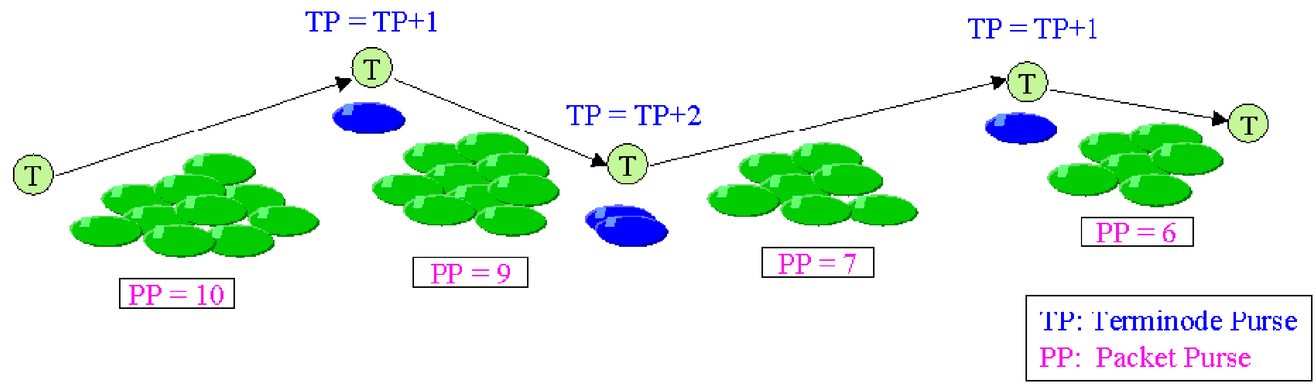

Fig. 2. Basic incentive mechanism. The packet purse is decreased of a number of beans that represents the cost for the processing terminodes to relay the packet. These beans are added to the terminode purse.

of the VHR is increased by A if no acknowledgment is received. When a terminode, say B, wants to talk to A (it must know A's EUI), then either it uses its last estimate of A's LDA, when it has one, or it sends a query towards A's VHR (which can be computed by B since the hash function H is well known). Fig. 1 illustrates the main operations of this mechanism. Methods to advertise the hash function and the radius of the VHR, as well as the scalability of this non-hierarchical scheme, will be studied in detail; if required, some automatic creation of hierarchies based on election of data repositories will be added.

Multicast packet forwarding in the Internet is already difficult enough and for terminodes, will be studied later.

D. *Incentive to Collaborate, Beans and Partner Networks*

The network relies on the collaboration of terminodes. In order to encourage such a behavior, terminode packets use *beans*. Every terminode has a purse of unforgeable beans, and every packet must be loaded with a number of beans sufficient to reach the destination. When a terminode relays a packet, it acquires one or several beans from the packet, and thus increases its stock of beans; the number of beans depends on the nature of the direct connection on which the packet is forwarded (long distance requires more beans). A basic example of this mechanism is given in Fig. 2. If a packet does not have enough beans to be forwarded, it is discarded. Cryptographic means to implement beans are under study, assuming that terminodes have some tamper-proof hardware that can be used for bean management. The terminode hardware comes with an initial stock of beans, and beans can be created by international treaty organizations and their agencies. The standard terminode beans have no monetary value.

Commercial operators may offer a service to terminode users, by putting at their disposal an infrastructure, possibly with high bit-rate cabled connections or satellites between them. This may be used as a mechanism to reduce the number of hops between terminodes in very dense areas (users would choose this option for voice), or also to go beyond empty areas such as the oceans. Specially encoded beans might be required for using such an infrastructure; commercial operators would then sell these beans.

E. *Terminodes and TCP/IP*

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; IP sees the terminodes as one huge physical network. Two terminodes normally use the TCP/IP protocol stack to communicate; however, inside the network of terminodes, packet forwarding does not utilize IP addresses (see above), just as bridges operate in a large bridged network. Host routes may be configured in terminodes in order to force a packet destined to another terminode to reach a gateway connected to the rest of the Internet. Solutions that work with IPv4 are for further study.

V. Application Scenarios and Discussion

Increasingly often, replacing a technology can be more cost-effective than enhancing it. The newer the technology, the richer are the potentials for new services.

Infrastructure-less mobile networks can be an appropriate solution in a number of situations. A first example is a natural disaster. An earthquake, a hurricane, or a flood can severely damage the wired and wireless infrastructure of a region. At the same time, the need to communicate increases dramatically in order to organize relief and assistance. Terminodes can be a way to keep communications being operational: even if some of them are lost or destroyed in the disaster, the remaining ones will spontaneously organize themselves to support the traffic.

A second example is related to political instability. Too often, because of a high level of corruption or because of guerilla activities, the communication network of a given region or country does not have the appropriate level of dependability. Such a situation can significantly hamper development and progress toward democracy. By empowering citizens with the networking functions, the terminodes can be an efficient solution to this kind of problem.

Terminodes can also be used for a wide range of applications in situations less critical than the ones described previously. As mentioned in section 2, they can serve to support a kind of "citizen band", by which people could avoid having to go through the infrastructure of a given operator – for cost or privacy concerns.

Acknowledgements

We would like to thank Christian Bonnet, Thomas Gross, Bryan Lyles, Bixio Rimoldi, Martin Vetterli, and all the team of the Terminodes project for interesting and useful discussions.

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