Proposal

Section 1: Scientific and/or technical quality, relevant to the topics addressed by the call

1.1 Concept and objectives

1.1.1 Main idea

This project proposal envisions taking a major next research step in building converged networks that deliver delay and disruption tolerant Internet services for nomadic and other use. The challenge in that work is considerable: A full solution requires the development of networking infrastructures which are pervasive, ubiquitous and highly dynamic, supporting a wide variety of nomadic interoperable devices and services, a variety of content formats and a multiplicity of delivery modes. To do this will require an opportunistic use of all possible connectivity methods, including Delay Tolerant Networking (DTN) connectivity. This is a major challenge to advanced architectures and protocols. Through a focused European cooperation around a well chosen real life template scenario (i.e., the every-day situation of semi-nomadic reindeer herders in North Scandinavia), and dissemination to standards organizations that will be involved throughout the process, taking this step and assuring its impact becomes a realistic goal.

The vision is further to create two test beds, one in northern Sweden and one in the mountain area in Slovenian, to test the system, to allow the verification of applications models and initiate deployment of the system. After the finalization of the project one test bed will have acquired competences and technology for future usage, that allow it to become a self sustaining resource to the further European development efforts.

1.1.2 N4C – topics of ICT call 2

The technical challenge addressed is intertwined with clearly defined socio-economic goals of inclusion of all citizens. Five billion people, a very large majority of the world’s population do not have access to the Internet. Among the European citizens who suffer from this lack of access, are people in rural and remote areas. Examples of such areas within the European Community can be found in isolated communities in northern Scandinavia, Slovenia, Rumania, and Poland in the Massif Central of France and in the Asturias and Galicia regions of Spain. Europe’s most remote rural areas have so much to gain from use of ICT and from being included in the Information Society. The EC target for i2010 aims to provide broadband and other ICT solutions which will give access to advanced public services and richer multimedia content for entertainment, training and work. With broadband connections, new forms of business innovation can transform the lives of individuals, increase social cohesion and contribute to economic growth in remote rural areas. Today access to broadband and ICT is not available in most rural areas. The cost of extending broadband services and ICT into remote rural areas is high which decreases the rate of deployment of eServices. A special problem affects areas which are so remote that technologies in common use are out of reach. For instance, we see this in nature reservation areas at high latitudes where environmental considerations rule out the erection of the masts needed for conventional mobile telephony and satellite coverage is inadequate or economically infeasible. Contrary to the conventional view, a range of activities of strategic, economic and social value do take place in such areas.

It may be a handy rationale to ascribe lack of access to regional circumstances or economic matters. However, the hard facts are that the lack of access facing the absolute majority of the world's population demonstrates the patent inability of current technical systems to offer competitive solutions for a large majority of usage scenarios. When viewing the 'problem' of *broadband and access to all* this way, it appears less as a problem and more as an opportunity for innovation. The attention paid by actors in Silicon Valley to the UN GAID (Global Alliance for Information and Communication Technologies and Development) signal that this view is already gaining traction within the industry in the USA. This was demonstrated clearly at the 'UN meets Silicon Valley' conference in February 2007 and also by the cooperation initiated in 2006/2007 between a major global Silicon Valley based networking company (CISCO) and the Arctic Council's Arctic Assessment initiative, which is formalized via the Institute of the North, signal that this view is already gaining traction within the industry in the USA. In March 15-16 2007, The Cisco Internet Business Solutions Group hosted a meeting for the Sustainable Development Working Group (SDWG) ICT Network in San José, California. The focused was on assessment of ICT in the Arctic, an activity that CISCO will continue to be involved in. In N4C project the template will be the exigencies of nomadic life in remote regions of northern Scandinavia referred to as Sápmi/Lapland and the remote and sparsely populated Kočevje region in Slovenia. By focusing on the practicalities of networking in the most challenged of areas, the goal is to produce advanced technology that can be used as a solution in many other developmental and operational problem areas, while achieving important European social goals.

1.1.3 Delay Tolerant Networking and the SNC architecture

A key role in N4C is played by the emerging Delay and Disruption Tolerant Networking (DTN) technology. DTN technology addresses a wide range of technical problems, from interplanetary applications to terrestrial applications where it is not possible to reduce latency to the values needed for today's Internet. Example applications range from methods of delivering information related to global warming to a means of including remote populations in the opportunities of modern Internet society. Expected urban use of DTN includes delivery of video on demand for the podcast generation and other consumer applications where streaming is not optimal for cost or other reasons. DTN can support asynchronous web surfing, email, file transfer etc. It also supports the capability of using different transport protocols in different parts of the network. Existing capability as included in the publicly-available DTN reference implementation (Fall 2005) operates as a store-and-forward routing and session layer protocol, creating network connections when appropriate, or re-creating them when they have failed. This is important for communication in remote areas because such communication normally has the combined characteristics of high delay, high cost, and high loss rate. These features combine to make our standard (TCP/IP based) protocols perform poorly as compared with the more ordinary wired LAN and WAN environments for which they were designed. The development of DTN technology is fully integrated in the standardization processes through the Delay Tolerant Networking Research Group within the Internet Research Task Force (IRTF DTNRG, currently chaired by Kevin Fall, Intel/Berkeley and Stephen Farrell, Trinity College Dublin).

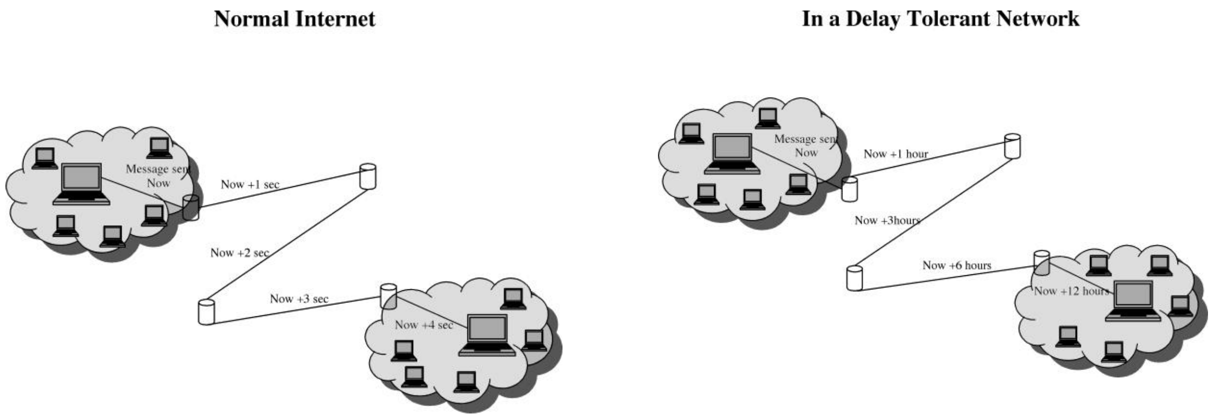

Figure 1.1 Contrasting Expected Delays in Conventional and DTN networks

The concept of using DTN for nomadic use in remote areas has been developed in the context of Sámi Network Connectivity (SNC). SNC is at once an Internet Architecture and a project, lead by the coordinator, since 2002. The work to develop and provide an initial demonstration of the SNC concept has been carried out by an informal team involving Sirges Sámi Village including the owners of TANNAK, the creator of the SNC architecture, Avri Doria and other participants in N4C, through funding from national and EU funds (regional, social and structural). It began as a project for the promotion of gender equality and economic development of reindeer herding, *Woman in the Sámi Village* (KIS) run by Sirges Sámi Village as an EU social funds funded project 2002-2003. With its 500 members, Sirges is the largest Sámi Village in Swedish territory. In the spring of 2002 Avri Doria, at the time a guest researcher at LTU, presented an idea on how to establish Internet connectivity to support the economic activity of reindeer herding to the NMKR and LTU/the coordinator. This idea came to be named Sámi Network Connectivity (SNC). A solution to serve Sirges has to address topographic circumstances (mountainous area), the fact that major parts of the Sirges territory is environmentally protected and should be preserved (which puts constraints on installing fixed infrastructure such as antenna towers and limits the availability of power sources), and the semi-nomadic nature of reindeer herding. A solution must also be accessible at an affordable and maintainable cost. The SNC approach to meet these requirements is based on the concept of Delay Tolerant Networks, realized by an Opportunistic Routing system using a mix of 802.11 hotspots and mobile relays. A solution that include a hybrid of the SNC realization of DTN and current Internet technologies, basic access to Internet communication services can be delivered to remote and nomadic communities. The initial goal was to provide e-mail and cached web access; the feasibility of this shown both conceptually and practically. More R&D efforts are needed especially to provide a seamless integration of the two technologies.

The basic SNC design involves using the DTN bundle protocol to relay data between gateways using opportunistic routing through fixed and mobile relays. The mobile relays periodically travel between the residential communities, meeting at points where data bundles can be exchanged and at locations where gateways, to the Internet are available. For use of the system in remote areas intermediate nodes are placed at chosen points. These intermediates are not connected to the Internet but serve to store and forward traffic from/to mobile nodes that pass the node even if not at the same time (passing travellers, hikers, aeroplanes, etc). This makes the delivery of messages from and to the Internet efficient even when few actual meetings take place, and this, in turn, makes the system useful for sparsely populated areas. While other ad hoc systems require actual meetings between individuals, the SNC architecture makes it sufficient that individuals pass the same geographical point. These points are chosen according to geography (topography, tracks, etc) or other criteria suitable for each system set up. The architecture is distributed: all nodes serve to forward the traffic and there is no central server. Within SNC, a routing protocol for this type of distributed mobile and intermittently connected network, PRoPHET, was developed, as well as prototype solutions to enable very basic email and web access. The architecture is illustrated in the Figure 1.2.

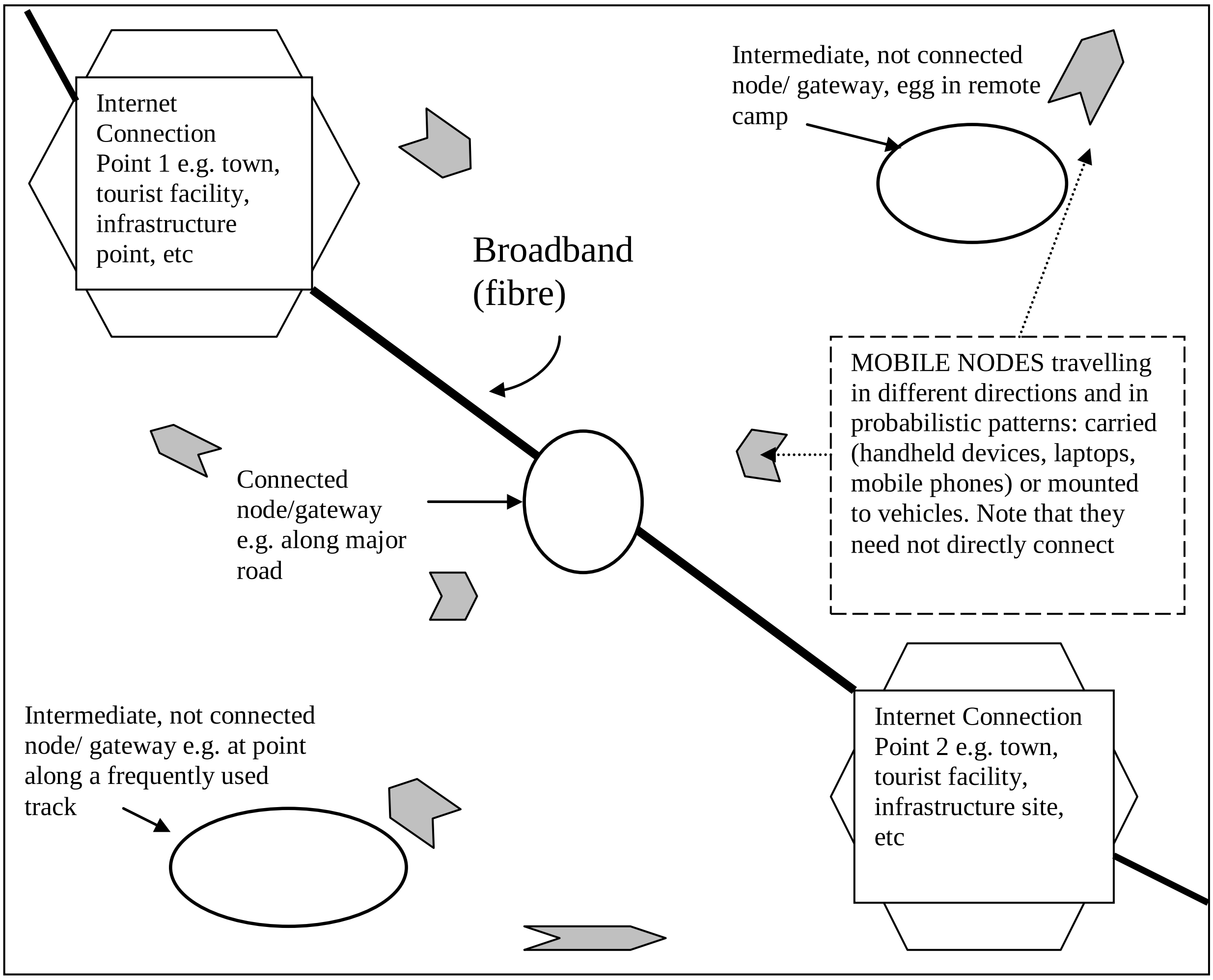

Figure 1.2: The general architecture with fixed and mobile nodes (gateways/relays) including intermediate nodes in remote locations.

The figure shows end user situations such as community or individual use of web, email and other Internet based services. The same principle is repeated in machine-to-machine networks, surveillance etc. The N4C effort aims to combine these different uses with a sustainable 'mesh' network. There are a number of detailed issues regarding the architecture shown in Figure 1.2 that were not completely addressed during the SNC project. These include completion of routing (which is enabled, for example, through the PRoPHET algorithm and protocol [Lin06a]) which needs to be extended to integrate the DTN portion into the conventional Internet coping with multiple gateways between the regions and development of
mechanisms for mapping between the addressing schemes in the DTN and the conventional Internet. Additionally there are security considerations that need to be understood and dealt with in the design. One suggestion for how to describe the logical structure of the scenario is shown in Figure 1.3.

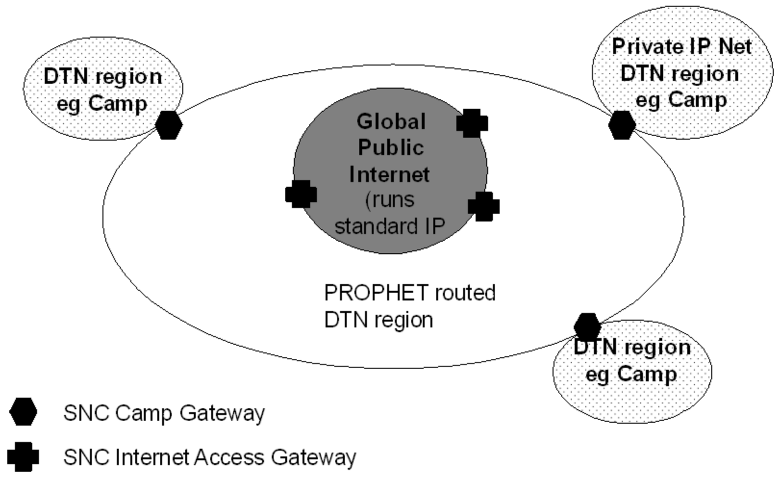

Figure 1.3 One example of how to describe the logical structure of N4C network scenario

1.1.4 Ubiquitous Networking

Ubiquitous networking is often spoken of in terms of traditional mobile telephony and wireless networks and is generally meant as allowing your program applications to follow you wherever you go. While this is a very fine goal, in most of today's ubiquitous networking projects this is confined to ubiquity within a very narrow area that has superior connectivity. The word ubiquitous, however, means: *present, appearing, or found everywhere.*[1] 'Everywhere' means that truly ubiquitous computing must extend to all those places that are outside the region of dense networking capability. This is a slight variation on the notion of ubiquity, taking the Internet to communications-challenged areas. Areas are considered challenged for a variety of reasons, for example, because even satellites don't cover the area, or because of war and other disastrous scenario, or because power cables don't reach there yet, or because governmental policy decisions don't allow for access. For the Internet to truly be ubiquitous it must cover all of the communications-challenged areas. Another use of the term ubiquitous, involves the development of appliances that have computing and networking embedded. In this context it means that computing capabilities need to become pervasive within all spheres of people's lives, including both work and leisure, so that their lives are improved.

1.1.5 Pervasive computing

The goals of pervasive computing involve making the lives of people living in remote areas easier though the use of networked appliance and other devices. Pervasive computing does not differentiate between the indoors or the outdoors, and it should not differentiate between communications rich areas and communications-challenged areas.

One of the extensions of pervasive computing into the outdoors involves adding sensor network capabilities that aid herders to track their herds without needing to physically follow the herds. For example, tracking reindeer in the winter is very labour intensive and interferes with the herder's ability to do other work or care for her family. Adding the ability to track reindeer and

[1]http://www.askoxford.com/concise_oed/

relay the information back to their mobile devices would do a lot to improve the economic opportunities for residents of marginal communities.

Another extension of the pervasive computing model involves bringing education, both schooling for children and continuing education for adults, to the people in their own space. A semi-nomadic population cannot simultaneously participate in the modern fixed location school system while living a traditional life. Using pervasive technology to help bring the school to the student will bring a form of harmony between the modern and the traditional and will do much to decrease the contradictions and stress of the semi-nomadic life. An important aspect of making people's lives easier, the goal of pervasive computing, is recognizing that technology must serve a population's culture and not try to force the culture into the prevailing technological box.

For pervasive technology to be truly pervasive, especially in regard to semi-nomadic and nomadic populations, it must locate itself, both temporally and spatially, within the remote and mobile natural world that is home to these peoples. In order to achieve the goals of pervasive computing in these remote areas, a number of existing enabling technologies and yet to be developed enablers, need to be combined into an opportunistic networking architecture.

1.1.6 Opportunistic Networking Architecture

For networking to enable both ubiquitous and pervasive computing it needs to be opportunistic and to use whatever access methods are possible. In a fully connected area, this means using the current commonly available cabled, terrestrial wireless, and satellite capabilities. In partially or fully communications-challenged areas it may also mean using new methods where the existing methods are unavailable or prohibitively expensive in the context of the activity that the communications are intended to enhance.

Utilizing opportunistic networking remains a difficult problem. As the industry has experienced in its efforts to converge the current telephony technologies into a single IP based network system, converging dissimilar technologies into a coherent network is very difficult. In order to take these converging legacy systems and extend them to reach the large number of people in communications-challenged areas adds to the challenge.

There are many locations in the world that are not within reach, or at least not within *affordable* reach, of the optical fibres, copper cables, radio waves or even satellite links that make up the physical infrastructure of the world's networks. Currently, being unable to reach this physical infrastructure precludes a user from accessing any of the Internet's services. Living in a communications-challenged area relegates the population to the deprived side of the digital divide. Many of the remote regions that this project aims to cover do not have reliable and affordable network access. In many cases there is no known network access, i.e., even satellite coverage is unavailable in much of the Arctic region. Also these areas are very large (the Arctic circle is over 1800 km from the North Pole) and sparsely populated so that propagation from the existing infrastructure needs to cover large distances in large hops with minimal resources.

The design of the original SNC project includes the possibly of using the dynamic nature of human movement as the primary vector for network propagation in the last 100 kilometres. Studies have shown that this model can work. When it does work, however, it does not produce a continuous connection, but rather creates an intermittent connection with varying amounts of message latency. In order to overcome the intermittent connectivity, a new form of network, Delay Tolerant Networking, is used. The bottom line of opportunistic networking includes the idea that if there is no other way of propagating information across the network, then a DTN can be used. Integrating DTN networks as another access method into the existing network infrastructure allows the Internet to reach people who are hundreds of kilometres, or more, away from existing infrastructure.

1.1.7 Communications within the DTN Regions

In communications-challenged areas we also find that there are usually limitations on the availability of power sources and often there are difficulties or constraints on deploying permanent infrastructure over these large areas. In some cases there may be security concerns where permanently deployed unattended infrastructure may be destroyed or vandalized. In other cases there may be cultural or environmental sensitivities restricting the scale and impact of any permanent deployments.

The earlier work in the SNC project explored a scenario with minimal impact on the local environment utilizing for most purposes short range Wi-Fi (802.11) communication apart from a single longer range point-to-point radio link connecting the trial area to the legacy Internet.
This proposal intends to explore technologies that

- can be used to deliver wireless communication at higher bandwidth (broadband capabilities) to gateways within the communication-challenged region using the limited power sources available and taking into account the topography and environment in the area (e.g., WiMAX (IEEE 802.16) or Flash-OFDM);
- can be used to implement low power local regional communications for groups such as the camps illustrated in Figure 1.3 above; and
- can be used to deliver content, possibly unidirectionally, directly to wider and more topographically challenging areas than is possible with currently deployed high frequency digital wireless technologies (especially Digital Radio Mondiale (DRM)).

Overall the project will have the goal of integrating a suite of technologies that will provide a competitive offering of broadband communication suitable for use in the communications-challenged areas that are the focus of the project, building on prior work both in the SNC project and from other projects that have addressed similar problems. This goal will include creating a sustainable test bed where future improvements in the technology can be made. Depending on the regional and national final response and other feasibility factors this test bed will either be an interconnected test bed in both regions or a test bed in one of the regions. Either way, both test bed areas will gain communications capacity even after the FP7 funding.

1.1.8 Applications of the Technology

From one point of view, the goal of extending pervasive, ubiquitous communications into currently communications-challenged areas implies that existing applications should ‘just work’ in the extended milieu. Hence one goal of the project will be to refine the understanding of the needs of such applications and their users and to ensure that the technology will allow them to work in the more constrained environment. To support the socio-economic aims of the project it is particularly important that educational, animal husbandry industry, and tourism support applications work effectively.
Going beyond existing applications, the project will also explore how the extension of the network into communications-challenged areas can be used to support appropriate novel applications. Four application areas will be addressed in particular:

- **Cached web access** allowing DTN users to receive all the information needed to display a particular web page or group of web pages through a single request made to a gateway in the legacy Internet. The objective will be to make this operation as transparent as possible to the user so that it appears that a standard web browser is in use even when synchronous retrieval of the information is not possible, and that the system is intelligent enough to deliver sufficient information to display the requested page(s) from a single bundle of information returned via the DTN. The project will also implement a 'push' model in which bundles of information can be pro-actively delivered to gateways within the DTN by the network either on a regular time schedule (e.g., to deliver news information on a daily basis) or as a result of actions by a user (e.g., packages of educational material appropriate to a particular student selected by a remotely located teacher).

- **Support for independent tourists** travelling within the communication-challenged region. Tourists would carry a specialized Personalized Digital Assistant (PDA) that would provide services appropriate for the region as well as acting as a relay for DTN messages to be forwarded in the DTN region. The project will develop applications and customize a PDA to support these functions. It is anticipated that the device may incorporate emergency beaconing mechanisms as well means to assist the tourist and emergency services in the event of an accident or other unexpected event. N4C envisages creating an application that could be downloaded to existing Linux- or Unix-based units or to mobile telephones with appropriate capabilities.
- **Remote sensing for meteorological and environmental monitoring.** These applications are important both in support of today's activities in these regions including animal herding and eco-tourism and also in support of longer term needs to monitor the environment in areas where local data collection is currently intermittent or non-existent. The International Panel on Climate Change (IPCC) has identified [IPCC07] the risks to the global economy from climate change, and there is a need to collect environmental data from all regions of the globe both to assist with immediate weather forecasting and to monitor the longer term effects on the global climate.
- **Animal migration monitoring. Some existing DTN work has covere**d monitoring of wild animal populations both terrestrial and marine. The project will extend this work to embrace the economically important species in the Arctic region. The reindeer herds that are the basis of traditional economic activity in the Sápmi region roam freely over **very wide areas. The projec**t will investigate cost-effective ways to monitor the location and other information about these herds and the individual animals. This is challenging both from the point of view of wide areas to be covered and the need to power any animal mounted equipment during extended periods during which solar power would be unavailable. Thus there is a need to study both the means to collect the data and the means to convey it automatically to the herders who need the information in a timely fashion. The achievements will be of value to cattle and animal tracking in general, and the results will be integrated in both N4C test beds.

The two latter applications generate data that may be delay-sensitive if it is to be used immediately (e.g., in weather forecasting) although the data will continue to be of value even if it is delayed (e.g., environmental data for longer term trend monitoring, herd locations from the recent past will give guidance to herds people). The project will explore communication mechanisms that might allow at least some of this data to be communicated more immediately than might be the case if it is necessary to rely solely on the DTN technology.

1.1.9 Security Aspects

The infrastructure of an opportunistically routed DTN of the kind envisaged here offers considerable potential for attacks on the integrity and authenticity of the data being carried. Relays will frequently be carried by persons who are not well known to the community and a malicious carrier would have ample opportunity to try and interfere with any traffic that they were carrying.

An additional objective will be to ensure that, so far as is possible, any data carried through the DTN is protected against unauthorized tampering and any private data will be concealed from inspection by unauthorized entities. Research work is in progress on adding security capabilities to DTNs and the project will investigate appropriate deployments of this technology in the context of communications-challenged environments. The challenges of deploying security technology in the scenario envisaged are considerable due to the wireless infrastructure, 'store and forward' operation, the problems of key distribution, the expectation that many users will not be highly trusted, and the lack of sanctions that can be applied to ad hoc users.

There are two additional security issues that require further research and development in order to meet the application and reliability requirements discussed above. Firstly, with DTNs being store-and-forward networks, and storage being a finite resource, there is sometimes a need to control access to that storage. In the Internet, this would be handled using an Authentication, Authorization and Accounting (AAA) protocol like RADIUS or Diameter. The project will therefore include work on a DTN AAA protocol, or more likely, a set of AAA extensions to the bundle protocol.

Secondly, DTN nodes are intrinsically highly vulnerable to denial-of-service (DoS) attack since they are generally 'exposed' nodes and cannot he 'hidden' behind a firewall. To make matters worse, a successful DoS attack on a DTN node can effectively 'kill' the node and seriously partition the network, since the typical recovery action (reboot) isn't easy with such scattered nodes. The project will therefore investigate additional ways in which DTN nodes generally, and nodes from the planned deployments can be made robust against DoS attacks.

1.2 Progress beyond the state-of-the-art

The current state-of-the-art in DTN is reported at length in the recent book "Delay- and Disruption-Tolerant Networking", [Far06] written by two of the TCD participants and is not covered in detail here. That book describes both a broad range of application contexts for DTNs as well as recounting the state-of-play in DTN protocol development.

As we shall see, progress in sustainable test beds is an aspect where the current state-of-the-art is somewhat lacking since most of the DTN projects to date could fairly be described as small scale short-term field trials. By incorporating applications that have real users, N4C intends to develop and run two interconnected test beds during the course of the project and create one sustainable test bed that can last beyond the initial FP7 funding.

1.2.1 Present state-of-the-art

Some of the most relevant aspects of the state-of-the-art in DTNs are presented in more detail below.

Future Internet Test Beds

The future Internet test bed with which the project participants are most familiar is PlanetLab (TCD operate a PlanetLab node) which is a distributed system of some hundreds of nodes where applications can be given a 'slice' of CPU and disk capacity on each node and can then run their application experiments. Since PlanetLab is essentially based on non-virtualised nodes, there are significant limitations on the types of actions experiments can take, for example, no experiment can require 'root' access.