Networking in the Land of Northern Lights - Two Years of Experiences from DTN System Deployments

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ABSTRACT

The Sámi Network Connectivity (SNC) project was started to enable Internet connectivity for the Sámi population of reindeer herders in the Laponia region in northern Sweden. In this area, no infrastructure and thus, no Internet connectivity is normally available. Thus, DTN functionality is used to enable connectivity through the use of mobile relays. This paper describes deployments and field tests done within the SNC project and its continuation SNC+1, in which a Delay-Tolerant Networking system was deployed in the target region. During these deployments, the PRoPHET routing protocol, and three different applications were deployed and tested sucessfully.

Categories and Subject Descriptors

C.2.1 Network Architecture and Design

General Terms

Experimentation

Keywords

delay tolerant networks, challenged networks, deployment

1. INTRODUCTION

This paper describes our experiences from two years of doing real-life deployments of Delay Tolerant Networking (DTN) systems. While this area of research have gained a tremendous momentum over the past few years, most work is still mainly theoretical, with a few exceptions[8, 14, 2]. Thus, we feel that it is important to try the technology in a real system, and also in the target environment together with the anticipated end-users. The Sámi Network Connectivity (SNC) project was run in various incarnations from early 2002 until 2007, focusing on establishing Internet communication for the Sámi population of reindeer herders,

who live in remote areas, and relocate their base in accordance with a yearly cycle dictated by the natural behavior of reindeer[12]. This population currently does not have reliable wired, wireless or satellite communication capabilities in major areas within which they work and live (or would prefer to stay if possible). During a week in August 2006, the SNC project conducted a first field test in the mountains of the Laponia region in the north of Sweden [6]. As the initial deployment was very successful, and the users wanted further testing, this was later followed by a winter field test (in order to test the usability of the equipment in extreme temperatures), and a second summer deployment during the summer of 2007 (under the name SNC+1). The technological solution that was tested during the first deployement week in 2006 had been developed in the SNC project in the years before that. After these deployments, the experiences gained were used to further improve the system for future deployments, and has lead to the creation of a follow-up project, N4C. This paper describes the two main deployments of the SNC and SNC+1 projects done during two consecutive summers and what we learned from them.

Figure 1: On-site "software development lab".

The SNC architecture makes use of the Delay Tolerant Networking (DTN) technology[11]. The basic premise is that in a hybrid solution with current Internet technologies basic access to remote and nomadic communities should be provided. The goal of the project was to create technologies that can enable the local population to have the same access to services and information as those living in more urban environments. This will give people new business opportunities and enable things like remote schooling, thus increasing the possibilities of continuing to live in the traditional way and locations. Our initial goal was to provide e-mail and cached web access, as many other services can be built on top of that. To enable this, application level gateways were

designed to enable the use of legacy applications in the SNC network. In the basic design, the data generated by these applications are then given to the DTN bundle protocol [11] 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. Within the project, a routing protocol for such networks, as well as solutions to enable e-mail and web access has been developed.

In the rest of this paper, we will describe the SNC architecture and the applications that we deployed in the system. We will then describe the two summer deployments in more detail and our experiences from those, and how the problems encountered, and the user experiences gathered from that has affected the evolution of the system and how that can help future deployments.

2. SYSTEM ARCHITECTURE

All gateways in the system ran the DTN2 reference implementation of the bundle layer protocol[11]. The bundle layer was used by the application gateways to send and receive bundles and to create a bridge between the DTN and the Internet.

To enable data to make its way through the network to the correct destination, we also had to develop a suitable routing protocol. Previous protocols for routing in intermittently connected networks such as the SNC network include for example Epidemic Routing[13], which sends the data to the entire network. As we wanted a routing protocol more tailored to the conditions of our system, we have previously proposed a *Probabilistic Routing Protocol using History of Encounters and Transitivity (PRoPHET)*[7, 5]. We used an implementation of this protocol on all the DTN gateways and mobile nodes.

2.1 User Applications

To make the deployment meaningful, applications need to be deployed that give the users some value from the network. Most applications that users are accustomed to are designed to be used over a network like the Internet, and thus will not work over a DTN. To enable the use of such applications in a DTN, there is a need for application level gateways that bridge between IP networks and the DTN and the bundling technique used there. During the deployments, there were three main applications that were deployed. In the rest of this section, the details for each of those applications are outlined.

2.1.1 E-mail

The first, and most obvious, application we selected for deployment was e-mail. This was believed to be a likely "killer app" for the SNC system. Email is one of the most important ways of communication on the normal Internet, and something that most users feel comfortable using. Due to its inherent asynchronous dynamics, is also very well suited to be deployed in a DTN network. It is also capable of carrying many MIME types, making it a suitable carrier for multiple types of data. While the protocols used for sending and receiving e-mail are interactive and not well suited for end-to-end use over a DTN, the characteristics of the e-mail service makes it easy to adapt to DTN settings.

To make e-mail work in the SNC system, and to enable e-mail messages to be sent over the DTN as bundles, an application level gateway was deployed at all the hotspot gateways, as well as on the Internet gateway. There was also a specially written SMTP server running on the machine that handled incoming mail for the domain used for mails during the test week, converting them to bundles and injecting them into the network. The gateways at the remote sites were preconfigured with the address of the Internet gateway, so all outgoing mail was sent to that address. Incoming mail was sent from the Internet gateway to all the remote sites, so all test participants could read e-mail at any of the hotspot sites. Users were able to send and receive e-mail either through the use of a regular mail program (e.g., on their own laptops, using the hotspot gateways as the mail server) or through a web mail interface that was installed on all hotspot gateways.

2.1.2 Web Caching

Supporting e-mail in a DTN system is fairly as easy it fits into the characteristics of the network very well, adding support for Web traffic is much more complicated. Web browsing on the other hand, tends to be a much more interactive task than reading and writing e-mails, and as such will also be more difficult to adapt for use within a DTN. During the test week, we deployed a web caching system that continuously fetched and distributed a predetermined set of web sites. Through this system, we could, for example, follow the events posted in the field test blog that was being updated during the test week (we were able to post pictures and other entries to the blog over the DTN through the use of a mail interface to the blog). Similarly to the e-mail gateways, the web caching gateway produced bundles containing the web site content, and sent the bundle to all hotspot gateways.

2.1.3 Not So Instant Messaging

In addition to offering the traditional applications of e-mail and web access, a Not So Instant Messaging (NSIM) service was also deployed. This application can be seen in Figure 2. As the name hints, the application is similar to Instant Messaging applications in the Internet, allowing users to exchange short messages (but the nature of the network, the messages become *not so instant* instead).

3. DEPLOYMENT SETUPS

3.1 Summer of 2006

The system used in the first field test consisted of a DTN core network, with fixed hotspots connected to its edges and mobile nodes serving as mobile relays within the DTN network to convey messages through the network. In order to enable communication with the outside world, there was also a gateway with Internet connectivity through a line-of-sight radio link to a nearby village. At the edges of the DTN, application level gateways in conjunction with DTN bundling software[11] was used to bundle application data into bundles that could be transmitted through the DTN. Within the DTN core of the network, the PRoPHET routing protocol[7, 5] was used to route bundles to their destination.

For this field test, both the gateways and the mobile relays consisted of Tablet PCs and laptops running Linux and Windows. As no regular mains electricity is available in
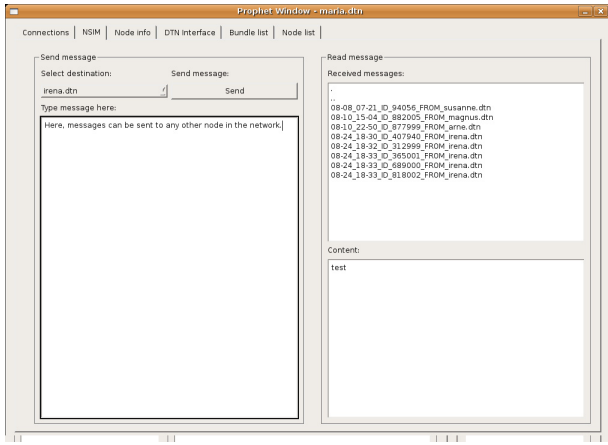
Figure 2: Not So Instant Messaging application.

the area, high capacity batteries in conjunction with diesel generators were used to keep the hotspots powered and to charge the batteries of the mobile nodes.

Figure 3 shows a map of the test area within the Padjelanta national park. Hotspots were set up at four different camp locations (Kutjaure E, Kutjaure W, Sallohaure, and Vastenjaure). From Sallohaure, there is approximately a 10 km hike to each of the other camp locations, and from Kutjaure E there is a 5 km hike to Sjpietjav. Between Kutjaure E and Kutjaure W as well as between Sallohaure and Vastenjaure, it is also possible go by boat. At each hotspot, a WLAN access point for clients, and a gateway which could be used for accessing and sending mail and web pages were deployed. In addition to these hotspots, the Internet gateway was deployed on the side of one of the mountains (Sjpietjav), where line of sight to the nearby village of Ritsem was achievable. This gateway was connected through a radio link to an Internet connection in Ritsem.

In addition to the stationary nodes, there were also seven mobile nodes in the system. The mobile nodes were carried by project volunteers who acted as data relays, hiking between the different fixed locations.
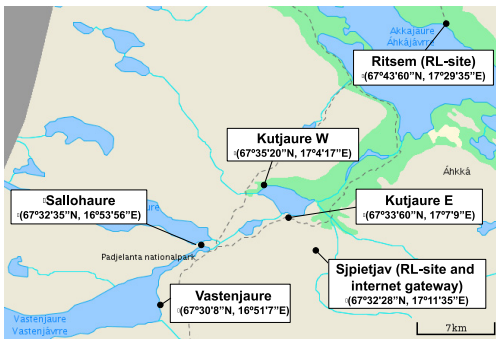

Figure 3: Map of test area, summer 2006.

Figure 4: Radio link used for Internet connectivity.

3.2 Summer of 2007

For the second field test that was conducted during the summer of 2007, the basic design of the system was the same as in the previous one, but with the changes outlined below. Based on previous experience and some tests done during the winter, the hardware of the system had been mostly replaced. The main hardware platform was now a x86 based platform called the WRAP in an aluminum encasing to protect it from environmental conditions. As a mobile user platform, a Nokia N800 Linux-based Internet tablet was also added to the system, and the system software ported to them. The Tablet PCs remained in use as user front-ends at the stationary nodes.

In Figure 5, a map of the test area for the second summer test is shown. Once again, Ritsem is used as the location of the Internet uplink, but the other sites have been changed to Saltoloukta and Staloloukta. As these locations are even more distant from Ritsem than in the previous deployment, it was not longer feasible to rely solely on hikers for data delivery. One of the benefits of the new hardware platform, and something that was desired to try out was that it was now possible to mount the WRAP devices on the helicopters that make regular trips up into the mountains, so that those can be used as carriers. Three WRAP nodes were mounted on helicopters. Due to a problem with the helicopters, initially the Staloloukta location could however only be reached by hikers with the N800 node, so service can still be provided without helicopters, but with higher delay.

In addition to the types of nodes tested before, we now also deployed a VPX sensing node in Staloluokta, measuring temperature and voltage levels and reporting this back through email. This is a first attempt at connecting a third-party device to the SNC system, which can prove very useful for many monitoring applications and other ideas.

4. DEPLOYMENT EXPERIENCES

As we concluded the first field test at the end of a long week, there was a consensus that the test had been a success. We had been able to achieve the main goals of the test, and had shown that the system designed within the SNC project can be deployed and work in the scenario that it targets. This section discusses the problems that were encountered during that test week, and lessons learned from the deployment experiences. We then describe what changes we made to the system in order to alleviate the problems discovered, and what our new experiences were in the second deployment.

Figure 5: Map of test area, summer 2007.

4.1 E-mail

As expected, the ability to read and send e-mail at the remote sites was very popular and quite well used. Overall, the testing of the e-mail system was successful, as it was possible to both send and receive mails at all locations. There were however still some issues with the e-mail solution.

Figure 6: Sending e-mail from a hut in the mountains while sitting on reindeer hides.

One problem with the solution that was quickly identified was that fact that all mails that were sent from within the system were automatically sent to the Internet gateway. This meant that e-mails addressed to addresses within the SNC system still was sent to the Internet gateway, and out on the Internet, only to come back into the DTN and find its way back to the hotspot gateways.

In the system deployed, all incoming e-mail messages were sent out to all hotspot gateways, as there was no way of knowing where a particular user was located. While this approach worked well during the test, it generates an unnecessary amount of traffic in the network, which could become a problem as the network grows in size, and more hotspot sites are added. There are two possible ways to alleviate this, and both methods could be used in combination to achieve the best result. To distribute the mail messages to all remote sites in this system, a separate unicast transmission of bundles to each remote site was used. If there were support for multicast in the network, bundles could instead be sent to a multicast address which all hotspots listen to, which would reduce the overhead in the network. A different way of reducing the number of bundles sent for each incoming e-mail is to only send the e-mail to the site where the user resides. This approach works well when users have a well defined home site, or stay extended periods of times at each site. It requires a system where a user upon arrival at a new site can send a registration request to the gateway for incoming mail containing the new location. At this point, all new incoming e-mails will be sent to the new locations. A message should also be sent to the previously registered location to ensure that any mail already sent there will be forwarded to the new location.

Another interesting observation (on the more humorous side) that we made regarding our e-mail system was that we did receive what might possibly be the first ever spam e-mail delivered over a DTN.

Based on these experiences, the mail gateway was updated for the second deployment. Functionality was added to ensure that emails addressed to another user located within the DTN part of the network did not have to go to the Internet first, but could be delivered directly to the user within the network. Functionality was also added to allow users to register themselves at one or more remote sites that they are likely to visit and have their mail pushed to those sites instead of flooded through the network. This registration functionality was however not used in the second deployment. Just as in the first deployment, this service was very appreciated during the second summer as well. In addition to offering the services to the regular population of the remote sites, tourists were offered to send electronic postcards to family and friends, which was very popular. Email within the SNC system had less latency than during the previous deployment as it did not have to go to the Internet gateway before it could be delivered.

4.2 Not So Instant Messaging

The NSIM application was initially developed as a debugging tool during the PRoPHET development, but as test participants started using the application during the first deployment, this quickly became one of the most frequently used methods for communication between test participants at different locations. The fact that the e-mail system at that point was designed such that all mail had to go through the Internet gateway, also helped make this application more popular as it was more efficient (had lower latency) than mail for communication within the DTN. Despite the fact that we solved the problem of internal email messages going through the Internet gateway, NSIM was kept in the system as a quick and easy way to send short messages to other users and remained a popular application during the second deployment for quick messages and to coordinate experiments.

4.3 Web Access

One of the areas that have the most potential for research is in providing web access. The caching system deployed during the first test week only provided a cache of a predetermined set of web sites. For the web access system to have more value to the users, a more dynamic web caching system needs to be in place. We have identified some features that should be present in a fully functional system:

On-demand fetching of web pages. When a user tries to access a web page that is not currently in the cache, the user should be presented with a message that the page is not currently available, but should also be given the option to have the page fetched for later access. In order to enhance the browsing experience for the user, not only the requested web page should be fetched, but in most cases, links should also be traversed and those pages be fetched (to a configurable link depth). More research is needed to determine which, and how much, additional information should be fetched to achieve the best tradeoff between user satisfaction and the amount of data that needs to be transferred.

Subscription to selected web pages. For certain web pages that are likely to be visited by users regularly, and that also are frequently updated (such as the web site of the local newspaper), it is inconvenient to always have to request an updated version. Therefore, it should be possible to subscribe to updates of selected web pages so that an updated version of that page is periodically delivered.

For the second deployment, we developed a new web cache based on the distributed WWWOFFLE cache, but this was still quite simplistic and much work remains to be done.

4.4 Routing and Addressing

Much effort has been put into developing the PRoPHET routing protocol, and during the field test, we were able to test it in a real scenario. During the test, the protocol were able to exchange messages and deliver bundles across the DTN core of the network. Deploying the protocol in the SNC target environment allowed as to study the protocol, and how it is affected by its parameter settings. Our experiences from the test week in conjunction with more extensive simulations of the protocol will help us understand the protocol better and make configuration recommendations.

For naming and addressing of the nodes in the DTN system, we use the addressing scheme defined within the DTN architecture[1]. This addressing scheme works well for the SNC system, but there are cases where it would be of interest to modify the semantics of it a bit to allow for the use of multicast and anycast addresses. As discussed before, multicast could be used to reduce the overhead in distributing e-mails and cached web content to multiple sites. Anycast support becomes of great interest when more than one Internet gateway is present in the system. When e-mails, web requests, and other bundles destined for the Internet is sent, the exact Internet gateway that the bundle is delivered to is not of interest, as long as the bundle is delivered to *any* Internet gateway. Fortunately, the design of PRoPHET makes it very simple to add support for anycast to the protocol. It is sufficient for each Internet gateway to just take part in the PRoPHET routing exchange, using the anycast identifier. Because of the way the routing metric is being calculated in PRoPHET, nodes will automatically choose the gateway that is "closest" (in terms of the routing metric) to themselves and send bundles towards that gateway. Recently, some work has been done, independent from the SNC project, on investigating the possibilities of using PRoPHET for multicast[10].

As the routing system worked well overall, there where no major changes in the functionality between the two deployments. For the second deployment, bundles were transferred through the network either by hikers, helicopters, or car (Saltoluokta is accessible by small roads). Initially, there were some problems with the routing as the bundles had too short lifetimes and would time out before being delivered. This was quickly discovered and adjusted at all nodes. One reason for the longer-than-expected latencies was that as the deployment had been slightly delayed, seasonal changes meant that fewer helicopters would fly into the area than earlier in the summer.

4.5 Hardware and Power Issues

One area in which we were able to make many new and important observations during the 2006 field test was regarding the hardware requirements for a system like this. The Tablet PCs and laptops used as relays worked fine for a proof of concept test such as this one, but in a permanent installation, another hardware platform is needed. It is important that gateways and relays are adapted for the rough environment that they be exposed to (including being shock and water resistant) in order to prevent malfunctions.

One major issue when operating any form of electronic equipment in an environment like this is the power constraints. As there is no fixed installations of power supplies, and things such as diesel generators are also only sparsely available (and due to the need to supply fuel and the added noise and pollution caused by such generators, they are generally not a desirable solution), opportunities to recharge batteries are scarce. Thus, it is important to choose hardware that do not waste power.

In order for the routing and forwarding in the network to work properly and automatically, nodes must be able to detect when other nodes are within communication range. Keeping nodes and their radios continuously powered up and performing neighbor detection scans consumes large amounts of energy and is thus an unfeasible solution in the long run for a system like this. One possible solution has been proposed within the DIESELNet project which would be applicable in the SNC system as well[4]. In addition to the regular computer and the high capacity radio, a small low-power device such as a Berkeley Mote with a low capacity, low-power radio is included with each data relay. Neighbor discovery is continuously performed by the low-power radio, and only when another node is discovered is the high capacity computer and radio powered up. This will maximize the battery lifetime while still ensuring that communication opportunities with other nodes will not be missed.

Quite a lot of changes were made for the second deployment based on our experiences here. The main hardware platform was replaced to one more suitable for the environment, and we were also able to test using solar panels to help power the devices. As that deployment involved attaching mobile nodes to helicopters, we were also able to get around the power problem for those particular nodes. Overall, the new hardware platforms (the WRAP and the Nokia N800) worked fine. There were however some minor problems, mainly regarding the powering of the nodes and things due to the human factor. As mentioned above, the frequency of helicopter flights was not as high as desired. This problem was further increased as it turned out that sometimes when the helicopter company needed the 12V power supply for something else, they would unplug our hardware, and not always remember to plug it back in, thus causing us to miss valuable data transfer opportunities. In the Staloluokta camp, a solar panel was installed (which can be seen in Figure 7), which helped with the power requirements up

there, but it would not generate enough power to be the sole source of power, so that site had some power problems.
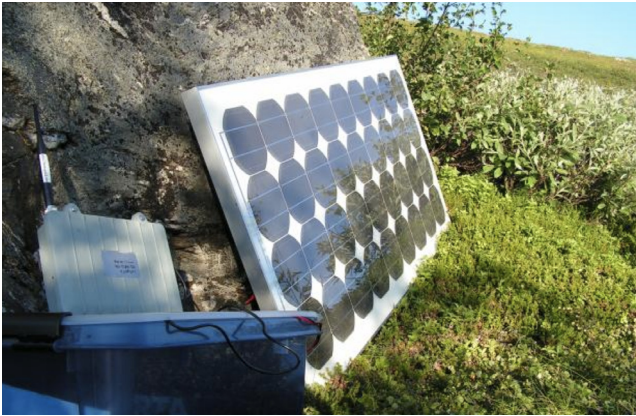

Figure 7: Some of the hardware for the second deployment. The WRAP is the small grey box to the left, and against the rock is the solar panel.

For future deployments, alternative options for power supply should also be investigated. Our first trial of solar power is a step in the right direction, as during the summers, there are many daylight hours per day (even midnight sun in the middle of the summer) in the region. As we saw, that was however not sufficient, and additional power sources are needed. An interesting possibility for deployment of solar panels, apart from placing them at the hotspots, include some recently developed solar powered backpacks[3], which could be useful for powering the relays. Yet another option for powering relays lies in a technology being developed at the University of Pennsylvania. Researchers have created a backpack that converts the mechanical energy from the vertical movements exerted when carrying the backpack into electricity[9]. While this still needs more work (in particular to reduce the weight of the system to become close to that of a regular backpack.

4.6 Interactions with Third-Party Devices

The VPX sensing device in Staloluokta was able to interact with the SNC platform nicely and could send temperature and voltage measurements by email to a monitoring account. It is good to see that it is possible to without great efforts connect third-party devices into the system and allow them to use the services provided. As monitoring of reindeer herds and environmental parameters are applications that are of future interest for the users, this is promising.

4.7 Other Issues and Observations

An important non-technical issue that is vital to the success of a system such as the one deployed during the field test is the population flow in the system. As data delivery is dependant on the mobility of relays, and thus the mobility of people, no data will be delivered unless there is a constant relocation. It is also important to note that while people might be willing to carry a relay on the hikes they would normally do, it is quite unlikely that they will do extra hikes, just to act as data relays. During the first deployment week, our Internet connectivity came through the radio link

on the Sjpietjav mountain. This is a location which was chosen solely for its line of sight communication possibilities with Ritsem, and which nobody has a natural cause to hike to (except to deliver and pick up bundles). Thus, the provision of Internet connectivity should be solved in another way in future deployments. During the second deployment, we removed the radio link and relied on hikers and vehicles (mainly helicopters) that go directly from Ritsem to the remote sites. Another possibility would be to use the large number of tourists that visit the area during the summer as data carriers in exchange of the use of the system.

5. OVERALL USER REACTIONS

The SNC project and related projects have always had the focus on the end user, and an important goal of the project was to leave a legacy that the user community can take and continue to build on and improve. While our tests have been proof-of-concept deployments, it is important that it does not stop there, as a quick deployment for a couple of weeks, but that it can be taken further. Therefore, the user community has been part of initiating the projects, and have been taking active parts in offering feedback and user requirements throughout the entire project lifespans. The people in the Sirges Saami village that have been our main point of contact with the user community and the facilitators of the test deployments were also taking a very active part as end users in the tests described in this paper. The users showed a great enthusiasm over the project and were very happy to be able to do things such as send emails to business contacts and catch up on the latest news from some news website from their summer camps in the mountains. They also see great potential for the future of this system and are continuing to work towards a more permanent deployment.

During the second deployment, use of the system was also offered to several tourists hiking in the Laponia region. These were also happy for the opportunity to send an electronic postcard back home to their families and friends in other parts of the world. This shows that there are also the potential to offer this service to tourists in the area, which is something that can both give revenue into the system by charging for its use. It will also improve system performance, as it will increase the density of mobile nodes and the frequency of contacts, which allows messages to be delivered quicker.

6. FUTURE WORK AND CONCLUSIONS

As outlined in the previous section, there are still many areas in which more research and more engineering is needed. Work in these areas will continue in an effort to create a system that is even better suited for the challenges that the environment offers.

The local Sámi participants in the field tests were very pleased with the outcome of the test, and have expressed an interest to host more field tests on a larger scale. A follow-on project to create living laboratories dedicated to this technology, Networking for Communications Challenged Communities (N4C) has been funded to create permanent installations that can serve both the local communities and researchers interested in applications testing in a DTN environment.

Acknowledgements

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