

Anders Lindgren
dugdale@sm.luth.se

Avri Doria
avri@acm.org

Olov Schelén
olov@sm.luth.se

Division of Computer Science and Networking
Department of Computer Science and
Electrical Engineering
Luleå University of Technology

Introduction

What to do if basic requirements for communication such as the existence of a fully connected path between the end-points fail to be fulfilled? Or what if the end-to-end delay of the system is longer than what TCP can reasonably handle? There exist several scenarios where this is the case, including communication between villages of the Saami population in the north of Sweden consisting of reindeer herders[1], and other aboriginal populations and populations in poor regions[2], but also scenarios such as satellite communication[3], sensor networking[4], and other areas where the Delay Tolerant Networking (DTN) architecture[5] is of interest.

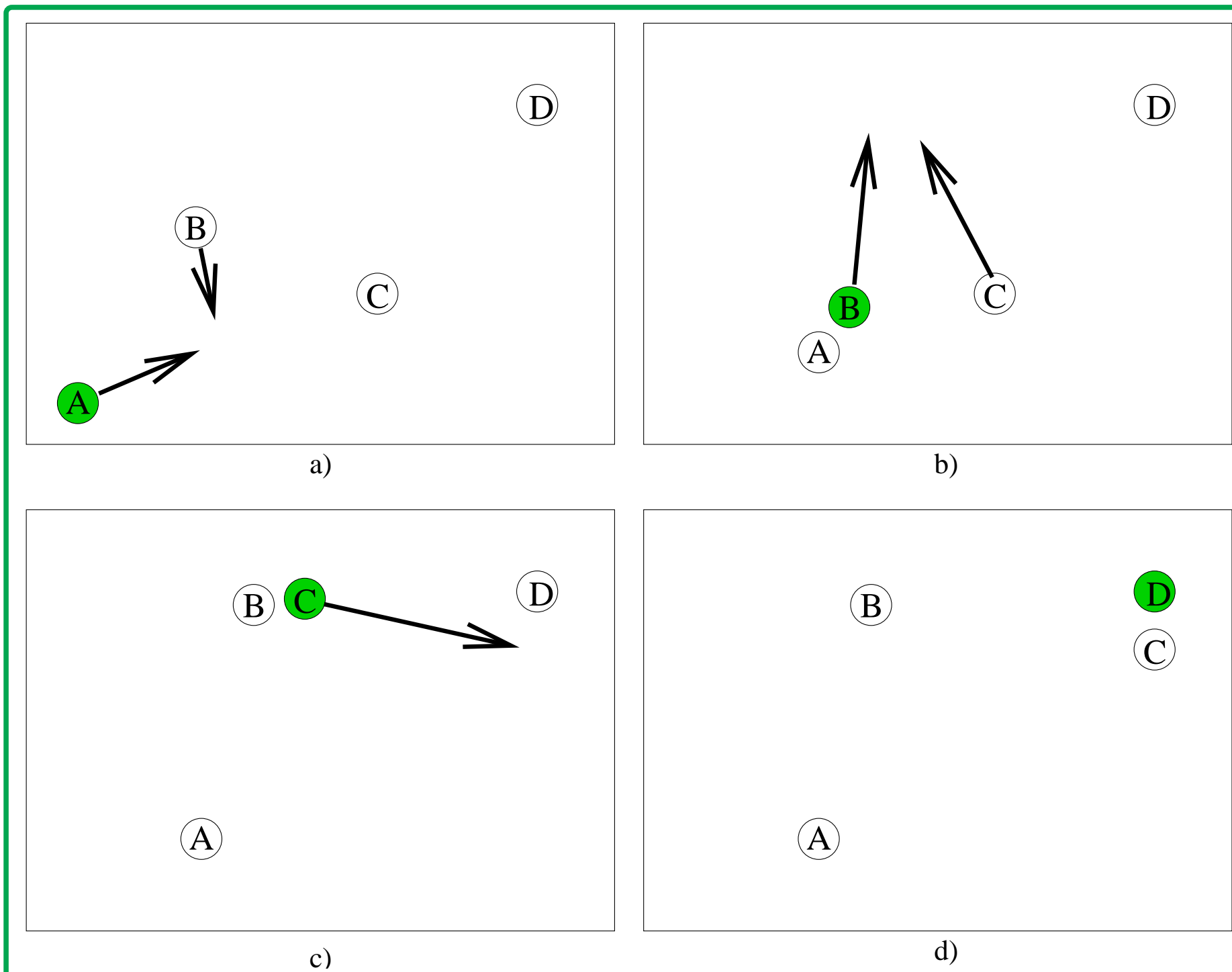


Figure 1. Transitive communication. A message (green color) is passed from node A to node D via nodes B and C through the mobility of nodes.

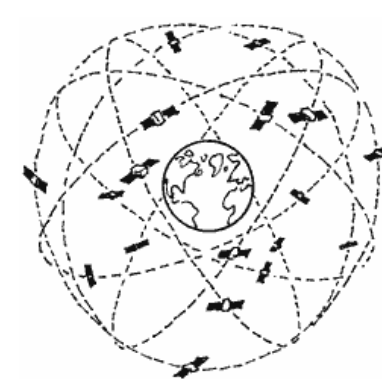
Figure 1 shows how the mobility of nodes in such scenarios can be used to eventually deliver a message to its destination. In this figure, node A has a message (indicated by the node being green) to be delivered to node D, but there does not exist a path between nodes A and D. As shown in subfigures a)-d), the mobility of the nodes allow the message to first be transferred to node B, then to node C, and finally node C moves within range of node D and can deliver the message to its final destination.

Related work

Vahdat and Becker present a protocol for epidemic routing in intermittently connected networks[6]. Hosts buffer both messages originated by themselves, and messages received from others for later forwarding. When two nodes meet, they exchange messages, causing the messages to spread throughout the network similarly to an epidemic of a disease (the messages being the “germs”, or contagious units).



Shen et al. propose a routing protocol for routing in an ad hoc space network with Scientific Earth Observing (SEO) satellites[7]. This differs from other kinds of satellite networks in that it is a dynamically deployed or configured group of satellites together with one or more earth stations. Further, there might not be a fully connected path between source and destination, so intermediate nodes might have to buffer messages until connectivity is achieved.



With an approach similar to the epidemic routing, Chen and Murphy studies the problem of communication in disconnected ad hoc networks[8]. In every step, a node searches the cluster of currently connected nodes for a node that is “closer” to the destination, where the closeness is given by a *utility* function that can be tuned by the application to give appropriate results.

Probabilistic routing

Normally, mobility is not completely random, but rather there is a pattern in the mobility of nodes that is also likely to be predictable, such that if a node has visited a location several times before, it is likely that it will visit that location again. We would like to make use of these observations and this information to improve routing performance by doing *probabilistic routing*.

To accomplish this, we establish a probabilistic metric called *delivery predictability*, $P \in [0, 1]$, at each node for each known destination indicating the predicted chance of that node delivering a message to that destination. When a node encounters another node, they exchange information about the delivery predictabilities they have and update their own information accordingly. Based on the delivery predictabilities, a decision is then made on whether or not to forward a certain message to this node.

As the protocol relies on the delivery predictabilities to support the decision of whether or not to forward a message to a certain node, it is important to determine how this metric should be calculated. The mathematical formulas used for these calculations are found in a separate space for the interested reader, and here only a brief overview is given.

There are three things of importance in the calculation of the delivery predictability:

Initialization

Perhaps the most vital thing to do is to update the metric whenever a node is encountered, so that nodes that are often encountered have a high delivery predictability.

Aging

If a pair of nodes does not encounter each other in a while, they are less likely to be good forwarders of messages to each other, thus the delivery predictability values must *age*, being reduced in the process. Figure 2 shows how the delivery predictability decreases over time due to the aging process.

Transitivity

The delivery predictability also has a *transitive* property, that is based on the observation that if node A frequently encounters node B, and node B frequently encounters node C, then node C probably is a good node to forward messages destined for node A to.

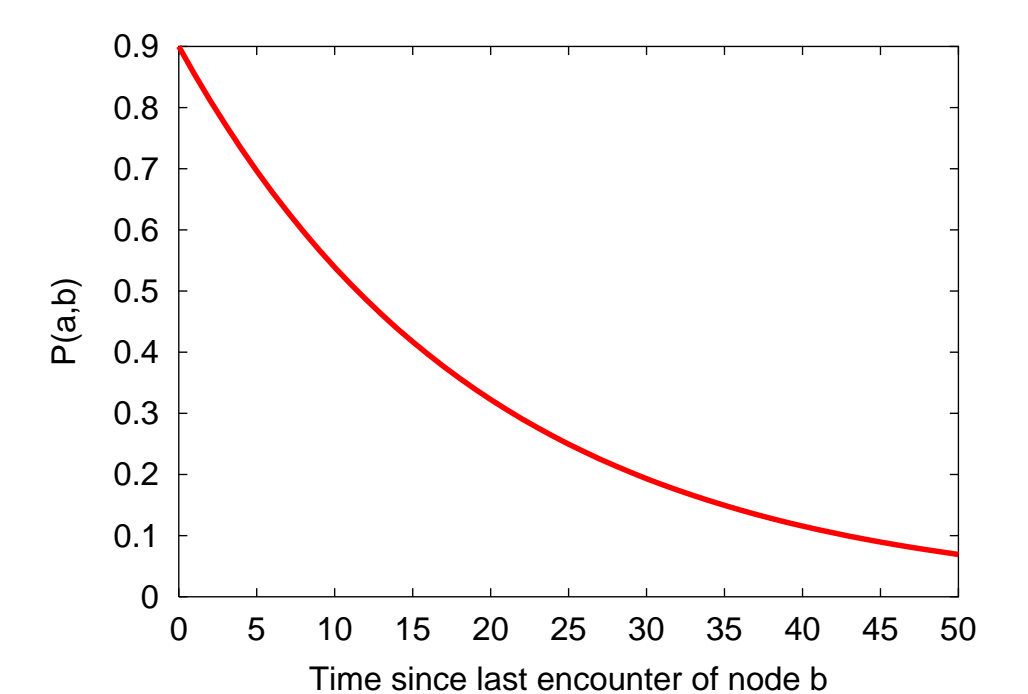


Figure 2. Aging of $P_{(a,b)}$

Equation corner

Initialization:

$$P_{(a,b)} = P_{(a,b)_{old}} + (1 - P_{(a,b)_{old}}) \times P_{init}$$

Aging:

$$P_{(a,b)} = P_{(a,b)_{old}} \times \gamma^k$$

Transitivity:

$$P_{(a,c)} = P_{(a,c)_{old}} + (1 - P_{(a,c)_{old}}) \times P_{(a,b)} \times P_{(b,c)} \times \beta$$

$P_{(a,b)}$ is the delivery predictability node a has for node b , P_{init} is an initialization constant, $\gamma \in [0, 1]$ is the *aging constant*, k is the number of time units that have elapsed since the last time the metric was aged, and $\beta \in [0, 1]$ is a scaling constant that decides how large impact the transitivity should have on the delivery predictability.

Decisions, decisions...

Once delivery predictabilities are calculated, there is still a difficult task ahead – choosing when and where to forward a message. The simple rules of traditional routing protocols such as “forward it to the node on the shortest path towards the destination” do no longer apply since there is no certainty about things as path lengths. All we know is that some nodes might be more likely to bring a message closer to its destination.

If a node does not know of a path to the destination when it receives a message, it must hold on to it and eventually forward it to some other node it encounters. Several things must be kept in mind when deciding who to forward a message to. First and foremost, the delivery predictability of encountered nodes should be considered. One strategy might be to keep a fixed threshold and only forward the messages to nodes with a delivery predictability over that threshold. However, in some cases there might not be any nodes with

high enough delivery predictability, so then this should be adjusted, or maybe even fall back to a scheme similar to the epidemic routing. Unfortunately, the task is not finished as soon as the message have been forwarded to some other node. There may very well exist cases where it might be sensible to forward a message to several nodes to increase the probability of delivery to the destination.

In the end it all comes down to tradeoffs. While giving all messages to everybody certainly would ensure expedient delivery of messages, large amounts of resources would be wasted (maybe even to the limit where not all messages actually could be delivered). On the other hand, being too strict on who to forward a message to, or forwarding to too few nodes would reduce the resource usage, but would harm performance in terms of delivery ratio and delay. Thus, exactly how to make these decisions is still an research issue, and the tradeoffs need to be thoroughly investigated.

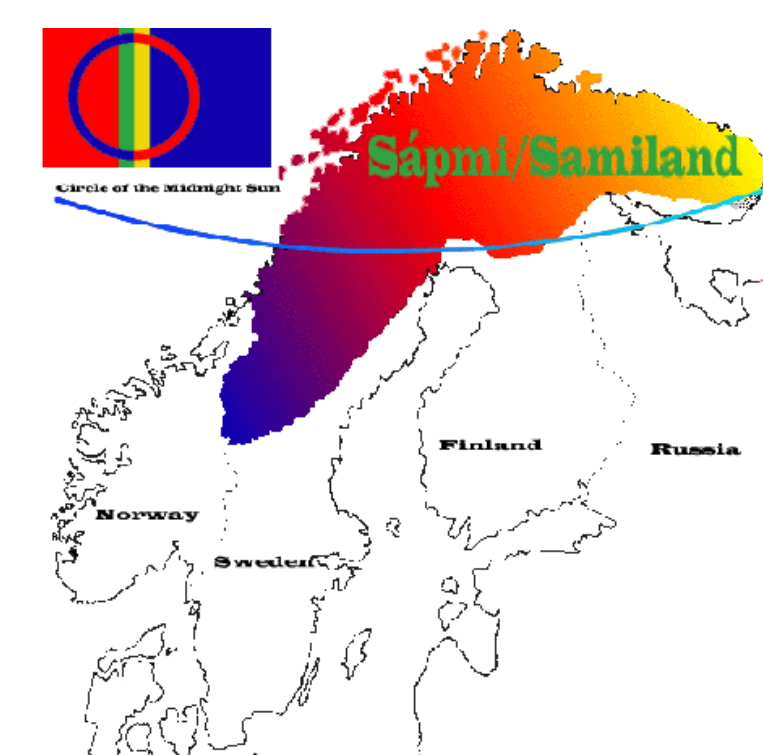
Future work

Since this is work in progress, there are still items that should be addressed in a not so distant future. The details of the operation of the proposed protocol will be specified to allow implementations of the protocol. It is of interest to minimize the protocol overhead, and to investigate the use of acknowledgements to purge messages from the network as soon as possible to free resources.

Extensive simulations of the protocol will be run to evaluate several aspects of it. Different parameter settings and decision making strategies should be investigated, and the equations chosen for updating the delivery predictability should be further studied to possibly come up with more suitable ones.

Saami Network Connectivity project

<http://www.cdt.luth.se/babylon/snc/>



The Saami Network Connectivity (SNC) project seeks to establish Internet communication for the Saami population of Reindeer Herders, who live in remote areas in Swedish Sapmi (Lapland), and relocate their base in accordance with a yearly cycle dictated by the natural behavior of reindeer. This population currently does not have reliable wired, wireless or satellite communication capabilities in major areas within which they work and stay (or would pre-

fer to stay if possible). A radical solution is therefore required, which is compatible with the Saami population's goal to uphold their land by being able to live there and care for the environment. The routing techniques described here are part of an architecture based on DTN[5] for that environment. The architecture involves application gateways at Saami villages and places of Internet connectivity, as well as mobile (e.g. attached to snowmobiles) and fixed relays used for the routing of messages in the network.



References

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