A Global One-Way Control Channel for Opportunistic Networks

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ABSTRACT

In this paper, we explore the challenge of limited global knowledge in opportunistic networks. Using a low bandwidth global one-way control channel, e.g., provided through the data side channel of FM radio, we mitigate this limitation.

In the case of Epidemic Routing in Delay Tolerant Networks, enhancing the acknowledgment mechanism for delivered messages using this channel improves message delivery by up to 50 % depending on the scenario.

Categories and Subject Descriptors

C.2.1 [**Computer Communication Networks**]: Network Architecture and Design—*Store and forward networks*

General Terms

Design, Performance

Keywords

opportunistic networks, control channel, epidemic routing

1. INTRODUCTION

Detecting if a message has successfully reached its intended recipient is a non-trivial task in opportunistic networks. As communication partners are only intermittently connected and end-to-end connectivity is generally not available, acknowledgements can take a very long time to arrive at the sender. Depending on the application, this may result in the need for significantly larger buffers.

In this work, we explore the potential of a global one-way control channel, in particular the RDS subsystem of FM radio, to distribute control information to distributed otherwise disconnected peers. FM radio covers large regions (80 - 160 km), potentially covering the complete deployment, while the low frequency of FM radio (87.5 to 108 MHz) does not suffer from attenuation, shadowing and other similar effects as typical short range radios in the ISM bands. However, this comes at the cost of a significantly reduced net data rate for the payload (230 bps), if we do not want to interfere with normal radio operation.

To the best of our knowledge, the idea of using a separate global out-of-band one-way control channel has not been explored in opportunistic networking research. Most of networking scenarios assume the existence of only one communication data channel between nodes in the network. Balasubramanian in her work "DTN Routing as a Resource Allocation Problem" [1] addresses the idea of maintaining a control channel in the network but she assumes an in-band channel as a sub-channel of the primary data channel.

We show, how, through the help of our one-way control channel, we can significantly improve message delivery rates in Epidemic Routing based networks.

1.1 Contributions

The main contributions of our work are:

1. **A global one-way control channel:** We utilize the RDS subsystem of FM radio as a one-way data channel to distribute control traffic in opportunistic networks.
2. **Alternative Network Architecture:** Using an additional control node connected to a FM radio station with a variable number of gateway nodes allows a more robust distribution of control data.
3. **Improvements to Epidemic Routing through global distribution of death certificates:** Through extensive simulations, we show that such a control channel can significantly improve the delivery rate of opportunistic networks.

2. RELATED WORK

We separate related work into three different groups. First, we look into data applications enabled by RDS. Next, we consider different ways to implement a control channel in opportunistic networks. Finally, we present death certificates as an extension to epidemic routing.

2.1 Pervasive applications using RDS

Rahmati et al. [9] suggest the use of the RDS communication protocol to support new kinds of pervasive mobile applications. Many of the today's mobile phones come with

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an RDS-enabled FM receiver[1]. Typically, this RDS channel is only used to receive simple information related to the running FM channel. However, the RDS protocol specification states that certain fields in the protocol frame can be used for custom applications. Examples of these applications are:

Value Added Services for FM Radio.

New value-added services can be broadcast to listeners using the RDS broadcast channel. These services do not need to be provided in a timely manner and therefore the low-rate RDS channel is sufficient to broadcast them. As an example, radio stations can provide the Electronic Program Guide (EPG) to its listeners. This will help the station listeners to schedule and record their favorite programs. Other items such lyrics album art and subtitles can also be broadcast via the RDS broadcast channel.

Promoting Station Loyalty.

Radio stations can utilize the RDS channel to increase the number of its audience. As an example, on-air advertisements can be combined with small texts, images, URLs to support the advertisements. Also, special offers and coupons can be broadcast to keep the audience tuned to the channel during the advertisements period.

Data Services.

Data services are normally provided to mobile users via cellular or Wi-Fi networks. However, certain types of mobile devices such as mp3 and video players are not provided with GSM or Wi-Fi connectivity but they are provided with FM receivers. As a result to the ubiquity of FM receivers, RDS channel can be utilized to provide delay tolerant data services when other technologies are not available. Information like weather forecasts, news, sports and exchange rates can be broadcast in simple text formats via RDS.

Query-to-Many, Response-from-Few.

RDS broadcast channel can be used to broadcast queries to the audience. The ubiquity and scalability of the RDS-channel makes it very suitable to such kinds of applications. RDS-channel plays an important role in reducing the cost of broadcasting. For example, broadcasting a query via the cellular network to very big number of users costs much more than simply broadcasting it via RDS. The users who are interested in responding can use another communication technology such as SMS as an uplink to send their response.

2.2 Control Channels in Challenged Networks

Most DTN routing schemes use a small fraction of each transfer opportunity to exchange meta data between communication partners. As an example, Balasubramanian et al. [1] suggest the use of an in-band control channel to exchange meta data about the global network state between the nodes in the network. The availability of the knowledge about the global network state can greatly improve the performance of the routing algorithms. However, this information is mostly unavailable in practical DTNs due to the dynamic network topology and the uncertainty of the wireless links.

A typical information exchange in above work includes: (1) The estimated connection schedule with other nodes, (2) an updated delivery delay for each of the packets originated by the node itself, (3) any updated information about other packets maintained by the node, (4) the average size of past transfer opportunities, and finally (5) a list of packets which have been delivered since the last exchange.

Compared to an out-of-band control channel, an in-band control channel suffers from the delayed propagation of exchanged information. Meta data is exchanged in the same opportunistic manner as the actual data. This leads to the staleness of exchanged information. Accordingly, nodes may not be informed about newly created replicas for the packets, newly delivered packets and newly updated delivery delays in a timely fashion.

Facilitating Routing and Control using the Cloud.

Wittie et al. [4, 10] propose a new architecture for opportunistic networks: *ParaNets*. The design includes a thin end-to-end control channel, based on GPRS or a satellite channel, which transfers control packets, but not the data packets.

Control traffic is characterized by its small size and by the necessity to have a complete end-to-end communication path. In contrast, the data traffic is characterized by its big to very big size. The small sizes of control traffic allows the use of long range networking technologies in which the bandwidth is restricted due to cost, policy or used frequency while the transmission range is long. Data traffic are transferred in big bulks so short-range networking technologies in which the bandwidth is not restricted can be used.

Using the additional always-on control channel, they are able to avoid problems, such as routing metric staleness that come with the long propagation delays typical in DTNs and show significant performance gains. However, the additional requirements of a second two-way communication channel might be prohibitive, depending on the application under research. In contrast, we make use of an already deployed albeit unused (one-way) communication channel.

2.3 Death Certificates

In his overview paper "Design Principles for Robust Opportunistic Communication", Keshav et al. [6] lobby for using *death certificates* as an acknowledgement mechanism for epidemic routing. They are a way to delete, i.e. *kill*, the messages which have been received correctly by the recipient, and can be thought of as an acknowledgement mechanism to empty message buffers, particularly when using Epidemic Routing.

Epidemic Routing works very efficiently at distributing messages at the cost of storage resources at all intermediate nodes. Resource restricted nodes may therefore experience buffer overflows continuously. The deployment may make use of buffer clearance policies, such as deleting the oldest messages, but this may result in a significant number of dropped messages.

A better way, to deal with stale message buffers, is to expel messages that already arrived at their destination. Death certificates, very small and easy to aggregate packets, can be distributed epidemically to clear stale messages on the participating nodes in a network.

In our work we combine the idea of death certificates with the approach of a separate control channel in order to avoid the negative effects of replicating the death certificates themselves and improve the speed of their delivery.

[1] This typically requires a headset, which acts as an antenna.

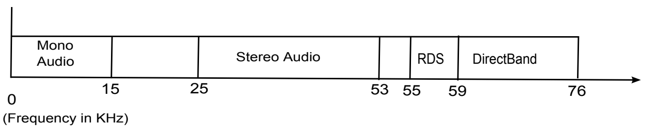

Figure 1: The division of the right half of an FM radio channel: FM stations use 15 kHz when working in the monaural mode and 53 kHz in the stereo mode. The remaining 75 kHz can be used by custom applications such as RDS and DirectBand. Source: [9]

3. DESIGN

We first discuss the properties and design of the RDS subsystem within the context of FM transmissions. Then, we present our system architecture, including a central, internet-connected control node at an FM transmission site, gateway nodes with an internet uplink, as well as normal nodes, with RDS reception capabilities.

3.1 Data Side Channel in FM Radio

FM radio broadcasting [9] is a radio broadcasting technology which uses Frequency Modulation (FM) to convey the radio signal over the carrier frequency. FM broadcasting uses a part of the Very High Frequency (VHF) radio spectrum, specifically 87.5 to 108.0 MHz. The line-of-sight transmission range of FM broadcasting is 80-160 KM with a transmission power of 100 kW, which makes it very suitable to cover major cities and populated areas. Frequency Division Multiple Access is used to share the spectrum between different FM radio stations. Each station is assigned a sub-channel of the total band. Two subsequent sub-channels are spaced at 200 KHz in order to avoid interference. Monaural mode uses only 15 kHz on each side around the carrier frequency. Stereo mode makes use of 53 KHz on each side. Figure 1 illustrates the division of the right half of an FM radio channel.

The Radio Data System (RDS) operates at an offset of 55-59 KHz to the station's center frequency. In the US, Microsoft operates the competing DirectBand datacast service, while RDS in a slight variation is known as RDBS.

3.1.1 Radio Data System Protocol

The RDS protocol is a communication protocol used by FM radio stations to embed digital information such as the name of the station in their radio program. Many mobile phones include RDS-enabled FM receivers, making this technology readily available. Using Phase Shift Keying, RDS has a gross data rate of 1187.5 bps. The effective data rate after applying error detection and correction is about 731 bps. RDS provides the capability to broadcast predefined data fields related to FM radio station and custom data fields.

These fields include:

- **Programme Identification (PI):** A unique 16-bit code assigned to each FM radio station.
- **Programme Service (PS):** An 8-character name represents the name of the station.
- **Program Type (PTY):** A 5-bit code represents the genre of the program. 31 pre-defined codes have been assigned to different genres of programs.

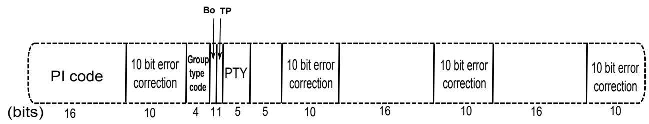

Figure 2: Fields of a RDS group: 16-bit PI, 5-bit PTY, 1 bit version code, 1 bit TP, 4 bits group type. The 37 remaining bits can be used for predefined meta data or custom applications.

- **Radio Text (RT):** 64-character of text informations which can provide information related to the running radio broadcast such as the artist and the name of the running song.
- **CT (clock time):** Can be used for the purpose of receiver's clock synchronization.
- **Traffic Message Channel (TMC):** The traffic information.
- **Open Data Applications (ODA):** *37-bit of custom data* allowing the development of new services and applications.

The RDS link layer groups data in blocks of 26 bits before transmission. These blocks consists of 16 bits of data and 10 bits for error correction, with four blocks forming one group, or RDS frame, see Figure 2.

RDS has a data rate of 1187.5 bps which is equivalent to 11.4 groups per second. Two of the available groups are reserved for Program Service (PS) and 3.2 groups are reserved for Radio Text (RT) which leaves 6.2 groups for custom applications. This leaves around 230 bps for custom application payload, if we don't want to interfere with regular FM radio operation.

We will see, that even with this very limited data rate, we can significantly improve the delivery rate, by freeing buffers on all intermediate nodes.

3.2 System components

Our architecture has three main components: a control node, gateway nodes and normal nodes. Normal nodes send a message, either to the Internet or to an arbitrary other node using epidemic routing. As soon as the message is delivered to its destination, the receiving node issues a death certificate to expunge all remaining copies from the network and forwards it epidemically. We can define death certificate as a small size packet holding only the ID of a successfully received packet.

As opposed to the original setup, presented by Keshav et al. [6], we now employ gateway nodes, that short-cut the delivery of death certificates to the control node via the Internet. Through this, the control node has global knowledge of all successfully received messages. In turn, the control node is connected to a powerful FM sender with RDS capabilities.

Via this RDS channel, we forward the death certificate of successfully received messages to all nodes in the network. The sender and all intermediate nodes can safely purge these messages, making space for other, newer messages. At the same time, we conserve bandwidth and battery resources, as stale messages do not need to be transmitted anymore. Figure 3 visualizes this process.

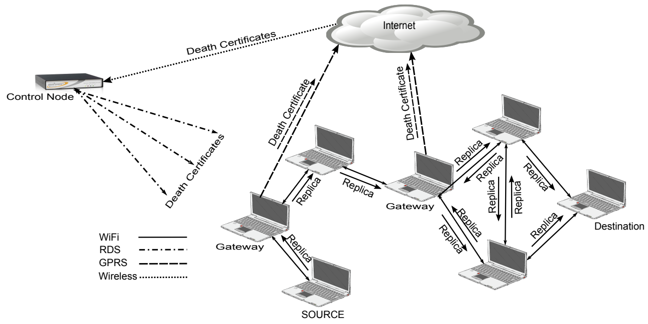

Figure 3: Death Certificates for Epidemic Routing: Gateway nodes are responsible for uploading death certificates to the control node. Upon receiving a death certificate, the control node disseminates it to all nodes in network via the global one-way control channel.

If a gateway node has currently no global connectivity, it acts as a normal node. Overall, we trade the number gateway nodes, which might have slightly higher energy expenditure with the network performance of normal nodes.

3.2.1 Uplink Technology for Gateway Nodes

We can use different communication technologies to implement the uplink to the Internet. Satellite uplink connect to the Internet via low Earth orbit (LEO) satellites is available virtually globally, depending on the specific orbit. However, in terms of cost, necessary hardware and energy consumption, a satellite uplink may not be an efficient solution [3].

Alternatively, we may use General Packet Radio Service (GPRS). GPRS has many characteristics which make it an efficient and suitable solution for providing an Internet uplink. Depending on the application and scenario, network coverage is good, while the technology is comparably cheap and low maintenance on the client side. Finally, the Short Message Service (SMS) of 2G and 3G networks, can often provide better service, at a smaller data rate.

4. EVALUATION

To provide a preliminary evaluation our approach, we used two traces: (1) the DieselNet traces, and the (2) Cabspotting traces. In the following, we will discuss our metrics and simulation environment. We characterize the performance of our approach compared to not using any secondary control channel and compared to all nodes having a secondary control interface, which is the ParaNets approach, see Section 2.2.

4.1 Metrics and Methods

Our main metric for comparison was the number of dropped, the number of relayed, and the number of delivered messages.

We define the number of dropped messages as the number of messages, that had to be discarded on an intermediate node, because of exhausted buffers. Similarly, the number of relayed messages counts how many relays happened in the network. A lower number correlates with less energy usage and more free buffer space. Finally, the number of delivered messages counts the number of messages that actually reached their destination, as the application layer effect of employing our approach.

Table 1: "DieselNet": values of the parameters for the first set of experiments

Parameter	Values
Number of Gateway Nodes	0, 4, 6, 9, 12, 15, 18, 21, 24
Buffer Size (MB)	10, 30, 60
Traffic Pattern (Message Generation Pattern)	1 message every 30 seconds 1 message every 100 seconds 1 message every 170 seconds

From these numbers, we derive the saving ratio, as the number of relays that could be saved, because a message was already delivered:

$$\text{saving ratio} = \frac{D_0 - D_N}{D_0} \cdot 100 \qquad (1)$$

where:
D_N: number of dropped messages when all nodes are gateway nodes
D_0: number of dropped messages when no node is a gateway

4.1.1 Simulation Environment

For all our simulations, we used *the One* emulator by Keränen et al. [5]. We slightly instrumented the code, to count dropped messages as well and enable a global one-way control channel, which we emulated as a low-bandwidth alternative channel on the nodes. Inputs to the simulator were connection (as opposed to location) traces, as well as traffic generation patterns.

4.2 Mobility Traces

We used DieselNet [2] and Cabspotting [8] traces. The only preprocessing was transforming to a format the simulator understands and randomly selecting nodes from the Cabspotting trace, as it was too big for our local hardware equipment to run with the simulator.

DieselNet.

DieselNet [2] is a delay tolerant network testbed consisting of 35 buses moving around the UMass Amherst campus and the surrounding area. The buses cover an area of about 150 square miles. Each bus is provided with a HaCom Open Brick computer with an 802.11b Access Point attached to it. Passengers and people nearby can have DHCP access using this AP. Each bus is also provided with a USB-based 802.11b interface to scan for other nearby buses and establish connections with them. A GPS unit is attached to each brick to record the location of the bus over time.

We conduct simulation experiments on DieselNet trace of 2007-11-05. It consists of 24 mobile nodes and lasts for 122675 seconds. In the first set of simulation experiments, we assign different values to each one of the three parameters and we study their effects on the values of the metrics. Table 1 shows values we assign to parameters. The first set of experiments consists of 81 experiments representing all the permutations of values of the parameters.

Cabspotting.

The Cab mobility trace [8] consists of the mobility traces of 500 cabs in the San Francisco Bay Area in the US. The duration of the trace is one month. Since the obtained re-

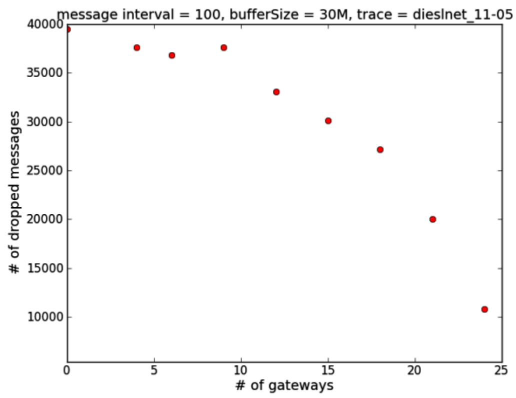

Figure 4: "DieselNet": The number of dropped messages as a function of the number of gateway nodes. The number of dropped messages is decreasing by increasing the number of gateway nodes which means better performance.

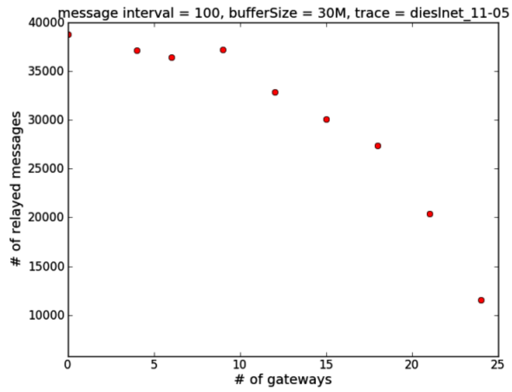

Figure 5: "DieselNet": The number of relayed messages as a function of the number of gateway nodes. The number of relayed messages is decreasing by increasing the number of gateway nodes which means less energy consumption and better performance.

sults were comparable, we will not discuss them in detail in this preliminary evaluation.

4.3 Number of Gateways Nodes

Gateway nodes are responsible for providing the control node with a global overview of the network. Different numbers of gateway nodes mean different degree of completeness of the global overview. We assign different values to this parameter starting from a scenario where all nodes are non-gateway nodes and finishing with a scenario where all nodes are gateway nodes. The worst case scenario where all nodes are non-gateway nodes represents a scenario where global one-way control channel has no effect on the DTN network. The best case scenario represents a scenario where the control node has complete global knowledge over the DTN network, cf. *ParaNets* [10]. As we use three different parameters in experiments, we can study the effect of the number of gateway nodes by fixing values of the other two parameters which are buffer size (30MB) and message generation pattern (1 message every 100 seconds).

Dropped Messages.

Figure 4 shows number of dropped messages as a function of number of gateway nodes. As we can see in the figure, the number of dropped messages decreases as we have more gateway nodes. The main reason of message drop in epidemic routing protocol is buffer exhaustion. When the buffer gets full, the protocol starts to drop buffered messages starting from the older messages which have been saved for a long period in the buffer. When the control node broadcasts death certificates, nodes in the network learn about delivered messages and then purge them from their buffers. This frees space in the buffer and leads to a lower number of dropped messages. By increasing the number of gateway nodes, we provide the control node with a more complete global overview and therefore more death certificates will be broadcast causing less number of dropped messages.

Relayed Messages.

Figure 5 shows the number of relayed messages as a function of the number of gateway nodes. As we see in the figure,

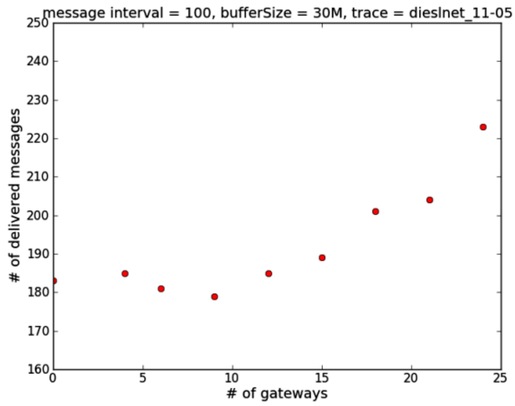

Figure 6: "DieselNet": The number of delivered messages as a function of the number of gateway nodes. The number of delivered messages is increasing by increasing the number of gateway nodes which means higher delivery probability and therefore better performance.

the number of relayed messages decreases with increasing number of gateway nodes. A less number of relayed messages means a less energy consumption in nodes. The replication of messages is the main reason of energy consumption in epidemic routing protocol. In the original epidemic routing protocol nodes may continue to relay a message even after delivering the message to the destination node. This is due to the lack of an acknowledgement mechanism which informs nodes about completed delivery of a message. Broadcasting death certificates through the control node enables nodes in the network to learn about delivered messages and therefore delete them from the buffer and stop replicating them. Therefore, our approach contributes in maintaining energy resources, possibly one of the most important resources in a mobile network, depending on the scenario.

Delivered Messages.

In Figure 6, we show the number of delivered messages as a function of number of gateway nodes. It is clear from the

Table 2: "DieselNet": number of dropped messages a function of the ratio between message generation pattern and buffer size.

ratio	0.5	2.5	5.0	7.5	10.0	12.5
worst case	152k	72k	48k	41k	41k	40k
best case	148k	55k	31k	21k	19k	15k
saving ratio [%]	3.63	23.56	36.32	47.41	53.97	62.36

figure that more messages are delivered with an increasing number of gateway nodes. This is directly related to number of dropped messages. As less messages are dropped, more messages will be able to reach their final destinations instead of being dropped due to a buffer overflow, resulting in a 50% improved delivery rate.

4.4 Effect of Buffer Size and Message Generation Pattern

The ratio of the buffer size of the nodes and the message generation pattern also have a strong impact on the performance. We study the effect of this ratio on the performance of our solution and compare between the best case where all nodes are gateway nodes and the worst case where no node is a gateway node. For each value of the ratio we calculate the percentage of messages which were successfully delivered as a result of the existence of global one-way messages. We call this percentage the saving ratio in dropped/relayed messages.

Table 2 shows a sample of the results we obtained with regard to the number of dropped messages. In the table, we see the number of messages, which were dropped because of full buffers, for each extreme case as a function of the ratio between the message generation pattern and the buffer size. We see that in the extreme case, we can achieve a more that 60% improved performance in our simulations.

As the ratio becomes bigger, i.e. more messages are generated compared to the buffer size, the advantage of our approach becomes more pronounced. However, to take full advantage of our approach, we need to choose the buffer size big enough to allow a time decoupling between sending and purging messages, which depends on the mobility and traffic pattern.

4.5 Discussion

While our initial study shows the possible performance gain of a global one-way control channel for Epidemic Routing using Death Certificates, this approach may proof to be also valuable for other routing schemes and scenarios, such as PRoPHET [7]. Similarly, we did preliminary work that suggests, that our approach is beneficial for DSR based networks as well.

4.5.1 Open Issues

This is a preliminary evaluation. There are a number of open issues, including:

- **Energy trade-off:** Depending on the secondary communication channel, the gateway nodes may have a significantly higher energy expenditure.
- **Real World Applicability:** What will the actual killer applications for opportunistic networks be, that make it worthwhile for a radio station to collaborate with the app provider. In turn, the application will drive the energy restrictions and bandwidth and traffic generation requirements.

5. CONCLUSIONS

We presented the idea of using the FM radio based RDS channel as a global one-way control channel for opportunistic networks. Through extensive simulations, we showed that this channel has the potential to significantly improve network performance with the example of Death Certificates in Epidemic Routing. More generally, this opens new design options when designing challenged network applications.

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