Optimized DTN-Routing for Urban Public Transport Systems

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Abstract

Communication is crucial to the coordination and efficient operation of public transport systems. However, deployment of infrastructure based communication systems is expensive, esp. due to long-term operational costs. Delay tolerant vehicular networks are a promising alternative since only very few infrastructure elements are required. This paper presents a DTN routing algorithm for urban public transport systems which exploits the knowledge about system characteristics and node mobility to improve the routing performance. Various DTN routing schemes are compared with the presented algorithm. Moreover, the impact of disturbances on the routing performance is examined.

Keywords and phrases DTN, Routing, Public Transport, RUTS, The ONE

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1 Introduction

Communication systems have a large impact on the efficiency and user-friendliness of public transport. Vehicle dispatching, traffic management, arrival prediction, dynamic passenger information and dynamic rerouting are just a few examples for processes that require communication. The increasing integration of information technology into the management and operations of public transport leads to a growing demand of wireless data transfer. Cellular data services provide sufficient range but relatively low data rates. Furthermore, the deployment and operation of a dedicated cellular infrastructure require relatively high investments. For the operator of public transport, permanent cellular access costs might be inhibiting. An alternative is direct vehicle-to-vehicle communication based on IEEE 802.11a/b/g/n/p. These WLAN technologies are capable of significantly higher data rates but also have a lower range, so it is unlikely that each vehicle is constantly in the radio range of other vehicles. This problem could be solved by roadside infrastructure, which would again require high investments. A delay tolerant network (DTN) is a more economical approach since for many applications a (slightly) delayed delivery of data can be accepted.

In a DTN, end-to-end connections are not required. Instead, the protocol data units, referred to as bundles, may be stored until a connection with the next hop is available. Then, the bundle is forwarded and stored again, and so on, until it finally reaches its destination. Choosing the 'right' sequence of next hops to minimize delay and maximize reliability is the routing algorithm's task. The proposed DTN routing algorithm takes advantage of the characteristics of public transport systems to improve the efficiency. In the next section the characteristics of contacts in public transport systems are analyzed. Based on this, the design of a specialized routing algorithm is described. In the evaluation, the routing algorithm is compared with various common DTN routings.

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2 Analysis and Characteristics

This paper focus on urban public transport systems with vehicles operating on surface infrastructure. Buses and trolleys running on roads or rails are the most common vehicles in such transport systems. These vehicles move on lines with stops. The arrival and departure time at each stop is defined by a timetable, which also defines the frequency of service on a given route. Usually, the frequency of service changes several times a day, according to a static plan based on the average number of passengers at a given time. For example, the frequency of service may be five minutes during rush-hour and 30 minutes during the late evenings. It should be noted that timetables are hard to maintain since unpredictable disturbances may happen such as traffic congestion, vehicle failures, traffic accidents or blocked roads.

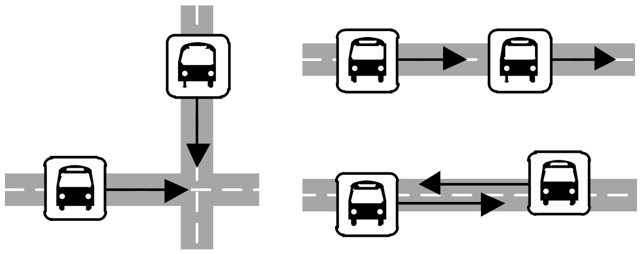

Figure 1 Left: intersection, Right: overlapping segments

A possible contact occurs whenever two vehicles are in each other's radio range. Vehicles move on lines and follow a timetable with potential contacts being roughly predictable. However, there are always minor variations, e.g. caused by traffic lights or changing numbers of passengers getting on and off at stops. In certain situations, these minor variations make the contact prediction very difficult. For example, a variation of just a few seconds can prevent a potential contact between vehicles of two different lines crossing at an intersection. For this reason, it is important to assess the probability and the duration of a possible contact. Currently, the routing differentiates between two situations which are shown in figure 1. The first situation is the crossing of two lines in an intersection in which the driving direction is insignificant. The contact probability and duration for this case is typically low. The other situation is where contacts overlaps in segments of the lines. In this case, lines overlap on a section of the map where vehicles can drive next to each other or one after another. The length and the direction are relevant for the contact probability and duration. Finally, combinations of these contact types are possible.

3 DTN-Routing in Urban Public Transport Systems

The goals in the design of Routing in Urban Public Transport Systems (RUTS) are resource-friendliness as well as timely and reliable delivery as far as possible in a public transport vehicular DTN. As mentioned before, there are some specific characteristics, e.g. timetables and network maps, which can be exploited for routing. If this context information is available on each DTN node, an efficient routing is possible. First, the possible contacts between the vehicles are determined and stored in a routing-graph. Based on this routing-graph, different ways from the sender to the receiver can be identified. Each way represents a possible routing path for a bundle. Due to external disturbances and local conditions, contacts have different performances and probabilities. Therefore, every contact involved in the routing paths has to be evaluated. This result is a rating for every possible routing path. Now, the bundle can be passed on to the most suitable path. Multiple copies of a bundles can be used to increase the delivery probability and to reduce latency. After the routing path for a bundle has been determined, it is stored in the bundle. Now, the routing path can be followed unless there is a discrepancy which occurs when a planned contact fails. Only in this case a new path has to be calculated.

3.1 RUTS Routing

At first, the number of bundle copies has to be determined which can increase the delivery speed and rate. As a result of unpredicted disturbances, it could happen that not every bundle can be routed on its calculated path. Therefore, n is defined as the number of bundle copies to be issued plus the original bundle. n is usually small and ≥ 1. For each new bundle, the transmitting node sets the initial value of n into an additional field in the bundle to save storage and transmission capacity for 'real' copies. As long as $n > 1$, the bundle may be split by a DTN node to follow a previously calculated path for each bundle copy. This means that a bundle is transmitted with an adjusted value of n to another node, whereby multiple transmissions can be saved. Now, both nodes have the same bundle and the sum of available copies of both parts corresponds to the value before. Over the whole bundle lifetime, it must be ensured that the number of copies in the DTN network is always $\leq n$. In addition to the splitting, it is still possible to forward bundles to follow the calculated paths.

In order to send the bundles and their copies on different routing paths, the different possibilities have to be detected. For this, k routing paths must be identified where typically $k > n$ to get a higher choice because each routing path can have a different quality. To find the necessary paths, RUTS uses the available timetables and the network map from the urban public transport system. This context information can be used to calculate possible contacts between vehicles. Each possible contact is stored in a special routing-graph. In the first step, the search starts from the sender DTN node. All possible contacts are inserted into the routing-graph. Now, the search will be resumed for all nodes contained in the routing-graph. The search is iteratively continued and is stopped if at least k potential paths are available. This routing-graph is explained in more detail in [1] and [2].

Now, the k fastest paths from the transmitter to the destination must be found in the routing-graph. As already mentioned, the paths vary in quality such as different contact probability and duration between the vehicles. Therefore, the paths are evaluated and the n best ways are selected for forwarding. In addition, a score value for each of the k-paths is calculated. It reflects the estimated time required for the transport from the sender to the receiver, the number of required hops and the line characteristics for each DTN node. All of the data can be obtained from the routing-graph and the available context information. The score for each k-path is determined as follows:

$$Score_k = \text{Time Difference} + \frac{\sum(\text{Contact-Rating})}{\text{Number of Bundle Transmissions}} \tag{1}$$

The time difference indicates the maximum transmission time of all paths minus the transmission time of the current examined path. For the rating of the contacts, the length of the overlapping or rather a fixed value for intersections is used. Each parameter can be parameterized to control its impact on the score. In addition, the rating models for the possible DTN node transmissions are interchangeable. After each of the k paths has been rated, the bundles are sorted according to the scores and distributed on the most suitable paths.

4 Evaluation

The RUTS routing was implemented for 'The ONE' [3], a DTN simulator featuring several previously proposed routing protocols which are used for performance comparison. For the simulation, realistic mobility traces with the real lines and timetables from the urban public transport system in Braunschweig are used. The studied scenario has been simulated for 5 hours, has 54 stops and 13 lines which are defined by a series of stops. For each line, one or several vehicles are assigned so that 28 vehicles are simultaneously on the lines. For the data exchange between nodes, the simulator generates a bundle each 5 seconds. Source and destination are random but are equal in each run. The RUTS uses a local copy of the timetables and the network map on each vehicle. In addition to the original bundle, two additional copies are used ($n = 3$). In the routing-graph five possible paths ($k = 5$) are determined.

4.1 Simulation Results

For the evaluation, various performance criteria are used to compare the different routing protocols. First, the number of successfully delivered bundles is considered as well as the bundles that never reached their destination because all bundle copies were discarded. Moreover, bundles may exist that have not yet been delivered because the simulation was terminated.

The next criterion is the average memory consumption at the nodes over the entire simulation. This value has an impact on the number of discarded bundles and the number of transmitted bundles. Furthermore, the average time to transport a bundle from the source to the destination is investigated. The number of delivered bundles has a direct influence on this value. Hence, these values must be examined jointly.

In figure 2, the successfully delivered bundles are illustrated as well as the lost bundles and the bundles remaining in transit at the end of the simulation. In the comparison of all routing protocols, RUTS can deliver the most bundles and also causes the lowest bundle loss. Figure 3 shows that RUTS occupies less storage capacity than nearly all other routing protocols. Only FirstContact uses slightly less memory in the simulation because it uses no additional bundle copies. However this causes a low delivery rate.

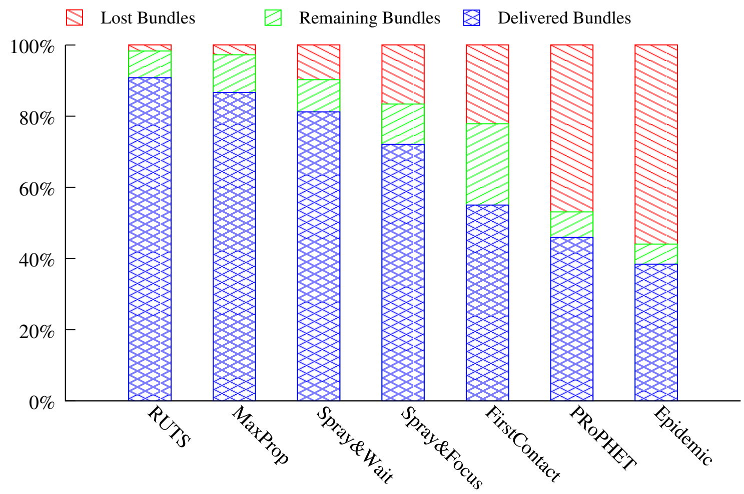

Figure 2 Lost, remaining and delivered bundles

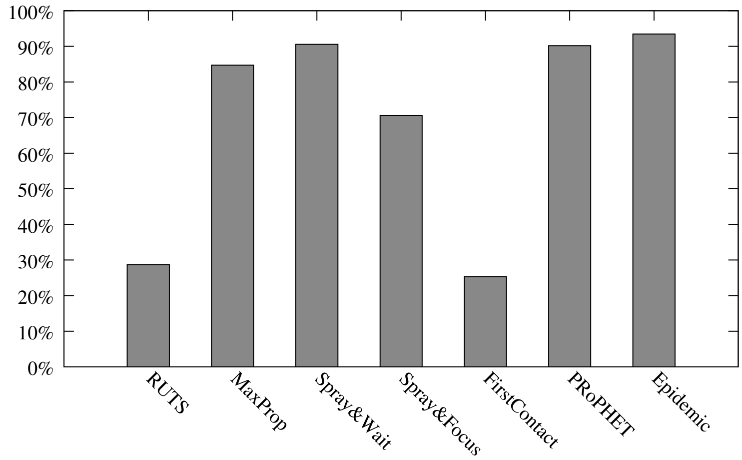

Figure 3 Average memory usage

Figure 4 compares the transmission times of successfully delivered bundles. Due to the random selection of the source/destination pairs, it is possible that bundles are generated on nodes which are in contact with the destination. These bundles can be delivered immediately, so that the minimum transmission time is very low. Average and maximum transmission times can only be calculated for bundles which are delivered before the simulation ends. Therefore, transmission time can only be interpreted in relation to the amount of delivered bundles because a higher number of delivered bundles increases the probability that bundles with high transmission times are included. In this context, RUTS achieves a low average transmission time, although it has the best delivery ratio.

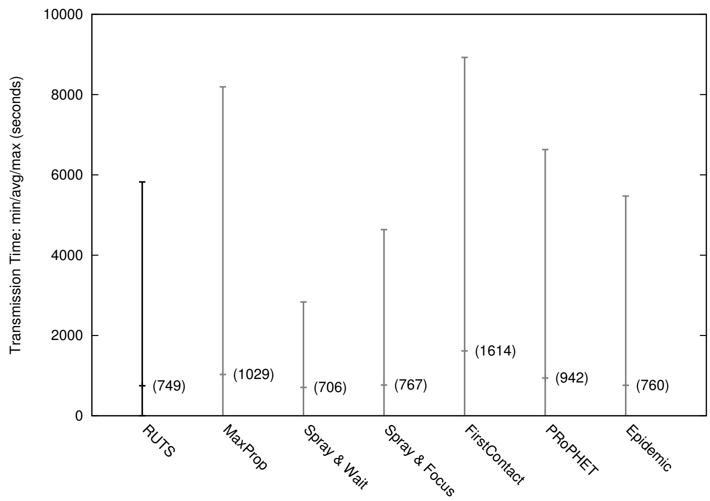

Figure 4 Transmission time (min/avg/max)

To investigate the impact of disturbances in the public transport system, several variations in the scenario were generated. 20% of the vehicles are chosen at random and are assigned a random delay of 1-5 minutes. Thereafter, the result is calculated as the average of several simulations. Figure 5 shows the differences between the previous results and the average results with random delays. Here, the differences are less than 1%.

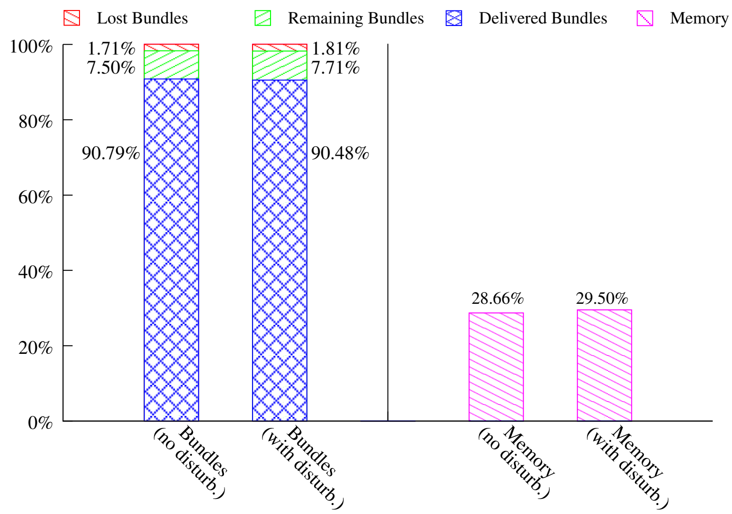

Figure 5 Impact of disturbances

The performance of RUTS is very promising taking into account all performance criteria. In all investigated areas, RUTS is at least similar to the best performing routing protocol. In most cases it archives the best results. Moreover, through the usage of some bundle duplicates, which are routed via another path, it is robust against disturbances.

5 Conclusion and Future Work

In this paper, the RUTS routing was presented which exploits the characteristics of urban public transport systems. The results show a low resource utilization, low latencies and high delivery rates. This is also the case if delays or breakdowns occur. In the future, major scenarios should be studied and simulated, e.g. the urban public transport systems in Chicago [4]. In addition, the scoring functions are further optimized.

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