# Design and Implementation of Co-Presence Transportation for Physical Objects

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***Abstract*—This work introduces a prototype for negotiation-based routing in co-presence networks. The Physical Object Sneaker Transport (P.O.S.T.) is aimed at forwarding physical objects towards their destination using local wireless communication devices (i. e., smartphones) for opportunistic route negotiation. The combination of existing data communication technology with the physical world provides not only interesting challenges, but may also provide novel methods for distributed authentication, payment systems and social networking. The prototype provides the basic functionality for further research and development of protocols and concepts related to spatial, distributed networking of physical and digital objects.**

***Keywords–Co-Presence; Opportunistic Routing; Emergence.***

## I. Introduction

We have developed an early prototype to support transportation of physical objects in a purely distributed manner using techniques from co-presence networking [1]. The general idea of co-presence networking is to exploit spatial movement of individuals and the occasional contacts between them to transport objects. A *co-presence network* is inherently a distributed network of contact events and unidirectional, ephemeral links between all participants. The scenario motivates research on a wide array of challenges and opportunities that emerge from the combination of distributed networking and corporeal co-presence.

This paper describes the ongoing work on protocol and prototype development for co-presence based transportation of physical objects. At this state of the project, the main objective is to show that routing and communication methods can be practically developed to enable peer-to-peer transportation of physical objects. The underlying objective is to provide a first platform that is based on spatial closeness relations and can prospectively be used to research authentication and payment in distributed, co-presence networks.

Network infrastructure has reduced the effects of and the requirements for spatial closeness in many forms of social interaction. There is, nonetheless, a tight relation between humans and their spatial and temporal location. Corporeal co-location generally is still the fundamental mode of interaction and the key source of social relations. One of the main objectives is to create an application which utilises spatial closeness in the digital domain.

The current version of the prototype is a very fundamental solution for peer discovery, co-presence opportunistic routing and integration of spatial attributes into the digital domain. The prototype is able to connect to instances of the prototype on other devices and negotiate an estimation of the best carrier, based on manually configured data about destinations of participants and objects. It already implements a basic model to protect location privacy by reducing the amount of disclosed information on destinations to a necessary minimum.

This paper is organised as follows: Section II introduces the scenario in the context of related work. In Section III, the protocol scheme is introduced. Section IV describes the architecture of our. prototype. A brief test of the functionality is summarised in Section V. Future work is discussed in Section VI. The paper is concluded in Section VII.

## II. Scenario and Related Work

The objective of P.O.S.T. is to transport physical — as opposed to digital — objects on a network of contact events and movements of physical entities, i. e., transport books, letters and other small goods by passing it to the next person moving in the right direction. The idea is that mobile devices establish a co-presence network, discover peers, negotiate routes and handle security protocols. The concept is comparable to Software Defined Networking, with the distinction that [2] human participants have to be involved to handle objects similar to the forwarding layer.

The idea has first been published in [3], where we undertook a first simulation to show general feasibility of the idea. But, co-presence networks are well known in the domain of transportation of digital objects. Transportation of physical objects otherwise is only found in centralised systems, e. g., ride-sharing agencies. Also, analysis shows that the network formed by encounters is scale-free, and thus can provide comparatively short paths for transportation [4].

Distributed transportation of physical objects is related to Delay-Tolerant Networks (DTN) [5]. Research on DTN is striving to engineer *data mules*. The objective of P.O.S.T. is aiming at *mules*, i. e., the transportation of physical — not only digital — objects. Known addressing and routing schemes, for example opportunistic routing [6], can be used to forward objects towards spatial locations. But also, direct addressing

 

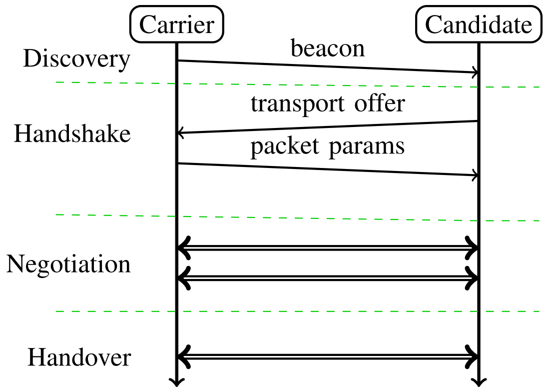


Fig. 1. Protocol Overview

of individual recipients, using *probabilistic routing* [7] can be imagined. While research on DTN for digital data is very well established, transportation of physical objects is, albeit comparable, rarely considered [8].

Routing decisions in this network are based on predictions of future location and contacts. This means that personal information — especially regarding location — has to be disclosed to peers. Formal models of location privacy provide techniques to establish a balance between privacy and efficiency [9]. Recent application concepts for contact-based communication, e. g., MoP-2-MoP [10], already address the topics of effectiveness and privacy for digital communication.

## III. Protocol Scheme

This section briefly introduces the four parts of communication of the P.O.S.T.-prototype: Discovery, Handshake, Negotiation and Handover. Participants then either take the role of *carrier* if the considered physical object is in their custody, or of *candidate* if not. This section describes the primary intentions and attributes of the protocol. The final communication standard is still under development.

The *Discovery* of devices that are P.O.S.T.-enabled is implemented by beacon messages. During the initial *Handshake* the candidate decides whether the attributes of an object, e. g., weight, dimensions, safety and security requirements, are agreeable by the user. The *Routing Negotiation* generates a decision about the optimal next carrier based on commitments to itineraries or destinations of participants and objects. The final *Handover* signifies the transfer of custody of physical objects. (See Figure 1).

### A. Discovery

The main obstacle for device discovery is to synchronise remote devices within a brief physical link duration [11]. Discovery of P.O.S.T.-enabled devices — in its current implementation — makes use of the Bluetooth Service Discovery Protocol (SDP). Bluetooth has been chosen, because it is wide available in smartphones. Every device subsequently alternates between actively scanning for devices or waiting for incoming connections. Waiting time is randomized by a parametrized amount. A P.O.S.T.-service is recognised if a connection on a common Universally Unique IDentifier (UUID) is established.

An established connection is then handed over to the Handshake protocol below.

### B. Handshake

An existing connection, i. e., the communication socket, is used for the *handshake protocol*. Both communication partners take on the role of carrier for all carried objects and the role of candidate for the objects carried by the partner. Starting with the client of the connection at first taking the role of carrier, a carrier sends descriptive data about carried object to the candidate. The data currently includes dimensions and weight of objects. This data explicitly excludes information on the objects or carriers destination which is exchanged only during negotiation.

The candidate then decides whether it is generally acceptable to carry this object. A negative decision ends the protocol for the current object. A positive decision lets both partners enter the route negotiation, described below, for this object.

### C. Route Negotiation

*Route Negotiation* describes the part of the protocol where the decision which of two partners will carry a given physical object onwards from the contact event. The protocol adheres to three principles to thwart attacks. The first principle is that the partner not holding the object must disclose his destination before the destination of the object is revealed. This order of disclosure makes sinkhole attacks more difficult. The second principle states that the final decision is made by the current carrier of an object. The current carrier is entrusted with custody of the object and already in the position to misuse this trust. The third principle demands that no partner will reveal movement predictions and destinations with a higher precision than the partner.

In the first message of the negotiation, the candidate discloses a current prediction of future movement to the current carrier. The precision of this spatial information is reduced to a defined degree to protect the user's privacy. The current prototype implements a prediction of the direction of movement which is cloaked by calculating a cone with a user-defined opening angle. The orientation of the cone is selected uniformly at random from all orientations that contain the original direction within the cone.

The current carrier of an object then decides whether the partner is moving closer to the destination than himself, not moving closer to the destination, or whether he cannot decide definitely. The first two outcomes lead to the termination of the routing negotiation with either a handover of the object following, or not. The third outcome of the decision leads to a request for higher precision sent to the partner not holding the object. The partner may now decide whether he accepts lower location privacy by calculating a new cone, contained within the previous cone which has a smaller opening angle. If a partner is not willing to increase precision of his movement prediction, the negotiation is terminated with a negative result.

### D. Handover

In the event of a positive routing decision, the object is handed over to the candidate. *Handover* is the only part of the protocol where participants have to be involved. The current handover consist of the transfer of data describing the physical object to the new carrier, i. e., dimensions, weight and precise destination. The transfer has to be acknowledged by both involved users. Only if the acknowledgements are communicated, the respective database entries are updated, meaning the former carrier deletes his entry on the object while the new carrier adds an entry to his database.

### *E. Location Privacy Protection Mechanism*

One objective in the route negotiation protocol is to reduce the amount of disclosed information of future destinations of participants to a necessary minimum. The Location Privacy Protection Mechanism (LPPM) [9] utilised here is obfuscation by reducing the precision of destination predictions exchanged with the communication partner. The current prototype implements destination as geodetic location, which is used to calculate the direction of predicted movement from the location of the current contact event.

To reduce the amount of disclosed information the protocol does not exchange the precise direction but a cone opening towards the direction of predicted movement. The opening angle of the cone is used as a measure of the precision of the disclosed information, i. e., the LPPM privacy parameter. The direction of the cone is chosen uniformly at random in a way that guarantees that the precise direction is included within the cone. It is further specified, that both participants disclose information with the same precision, emphasising the equality of both partners in the exchange.

Negotiation is initiated with a user-determined wide opening angle and successively reduced if, based on the disclosed cone, no decision can be reached. The prototype ensures that the opening angle is never reduced below a minimum privacy level as defined by the user. The result of a routing decision, based on a disclosed cone thus has a ternary result. If, finally, the minimum privacy level of either of the participants is reached with no definite result who the best carrier for a given object is, the object is left with the current carrier.

As the chosen privacy level is controlled by the user, the project is not yet able to determine to what degree the LPPM is reduces the quality of routing decisions. This topic is an interesting part of future analysis of the whole socio-technical system.

## IV. PROTOTYPE

The project has implemented a prototype for the android operating system that provides the core functionality of P.O.S.T., namely peer discovery, routing negotiation, handover, as well as a related database and a user interface.

The architecture is an extension of the model-view-controller (MVC) primitives [12], introducing a separate user service. The common primitives are represented by database, main service (dæmon) and User Interface (UI). Figure 2provides a structured view on the main components of the prototype.

*User Service* and *Database* are combined into the model-component and provide the complete state of the local system,

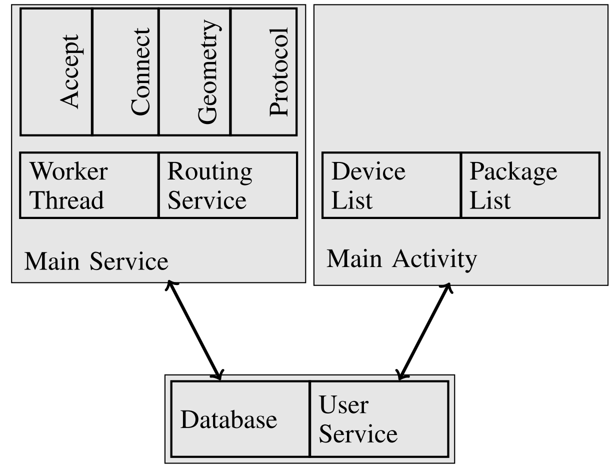


Fig. 2. Prototype Architecture

which contain the user's intentions, including privacy configurations. Within the database currently carried objects and data on the communication status of known devices are stored. In the future, the database will be extended to contain data to authenticate users and handle handover receipts. The idea is to utilise semantic vocabularies and methods to improve the integration into the physical world.

*Main Service* and *Main Activity* are structured following android implementation recommendations. A *Worker Thread* within the Main Service handles discovery of devices and runs through necessary handshakes alternately using *Accept* and *Connect* subroutines to establish communication. The routing process is then handled by an additional *Routing Service* in order to allow for concurrency, supported by necessary *Geometry* and *Protocol* instances. The *Main Activity* provides views on known devices and carried objects to the user, as well as providing the configuration interface to the *User Service*.

## V. TEST RESULTS

The project executed some primary tests that verified that the prototype provides the intended functionality. Tests where executed as a small field test with five individuals carrying P.O.S.T.-enabled smartphones simulating multiple contact-events at a crossing. We tested that communication between devices takes place and that routing negotiation produces the expected results. It could not yet be tested whether objects are indeed propagated over multiple hops.

For the current state of the prototype, the main problem seems to be peer discovery. During the tests with multiple devices, only a fraction of the present devices were positively identified as P.O.S.T.-enabled. Repeated laboratory tests identified mismatched accept- and connect-phases of the discovery protocol. Results from Nayebi and Karlson [11] suggest that the accept-time must adhere to the physical link duration in pedestrian situations.

The tests further identified usability of the prototype as one of the main obstacles for its success. The participants were dissatisfied with manual enrolment of objects. The suggestions hinted towards better automated support for selection of participant destination, object destination and identification of objects during handover. It was further deemed unsatisfactory, that the objects where handed over to "strangers" without any receipt.

## VI. Future Work

The main contribution of the prototype is to provide the context to a rich selection of challenges. Distributed networking in a co-presence world may be natural for human interaction, but it poses very fundamental problems for digital devices. On the other hand, the research community does not seem to have used the advantages and attributes of spatial closeness for security related operations, e. g., validation of identities for authentication.

Among the base communication problems, the peer-discovery is the most urgent problem to solve. The Bluetooth-solution seems to be a dead-end in this respect, but common mobile devices lack a dedicated channel usable for peer discovery. There seem to be two different approaches to be followed here: improving multi-channel communications, i. e., protocols to manage hand-overs from discovery to communication mediums and the exploration of unusual communication mediums, e. g., utilisation of ultrasound or light, depending on circumstances.

The routing scheme must be extended to realistic routing based on road maps. In the next iteration, routing on combined address-spaces, e. g., symbolic, personal and geodetic, will be incorporated. Symbolic representations, i. e., names of places, are better known to users, but the actual destination of an object usually is an individual person or organisation. Distributed transportation may provide a way to reach even mobile destinations of physical objects, the so-called *probabilistic-routing* might be utilised within P.O.S.T..

To enable the routing in this context, a precise prediction of future movements of an individual are fundamental. The main hindrance probably is the computational cost attached to predictive heuristics. It is nowadays common for individuals to provide precise predictions while using navigation software, but a person rarely uses navigation under every day circumstances on known territory. The project intends to use or develop algorithms that detect and exploit regularly visited locations for predictions.

The remaining area of research where the prototype provides a motivating and enabling platform is the wide field of physical security. We identify a need to physically secure the objects against damage and theft. We further require secure proof-of-work schemes to allow for payment or reputation systems. Further, without authenticity, there can be no accountability for lost objects and no penalty for stolen goods.

The project intends to use the prototype to research ways to exploit spatial closeness for authentication and the establishment of reputation. It has been shown by others, that spatial closeness and social relation are in correlation to each other [13]–[16].

## VII. Conclusion

This paper introduced a protocol and prototype for transportation of physical objects on co-presence networks that are still under development. The P.O.S.T. prototype provides the basic functionality for minimum-angle routing on geodetic coordinates. This paper discussed a list of areas for research that are opened up by the scenario and whose development is supported by the prototype.

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