Robust Communication for Agricultural Process Management in Rural Areas

How dynamic Combination and Configuration of Communication Technologies enables robust Data Transfers in Rural Areas

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Abstract

Management of agricultural processes is often troubled by disconnections and data transfer failures. Limited cellular network coverage may prevent information exchange between mobile process participants.

The research projects KOMOBAR and ISOCom designed, implemented und field-tested a delay tolerant platform for robust communication in rural areas and challenging environments. An adaptable combination of infrastructure-based cellular networks and infrastructure-free multihop ad hoc communication (WLAN) leads to a variety of new communication opportunities. Temporal storage and forwarding of data on mobile farm machinery as well as dynamic platform configurations during process runtime strongly enhance reliability and robustness of data transfers.

1. Motivation

In modern agriculture, sophisticated information technology is used for management and optimization of complex processes (e.g. harvesting corn, cereals, or potatoes). Data needs to be exchanged in a timely, reliable and continuous manner. This is essential for efficient adaption of agricultural operations regarding economic and ecological aspects. However, communication in rural areas is often characterized by disruptions and failures due to the mobility of participants (nodes) and limited cellular network coverage. Operation of agricultural process management is heavily challenged by unreliable data transfers since many management tools require reliable connectivity to mobile nodes.

2. Hybrid Communication Platform

The research projects KOMOBAR (funded by AGIP) [1] and ISOCom (funded by EFRE) [2] introduced a delay tolerant platform for communication in rural environments. Robustness of communication is increased by combining cellular networks with ad hoc and delay tolerant communication (cf. Fig. 1). Discontinued communication paths no longer result in transfer failures. Instead, alternative transfer opportunities are identified and used for communication. The different parts of the platform are described subsequently.
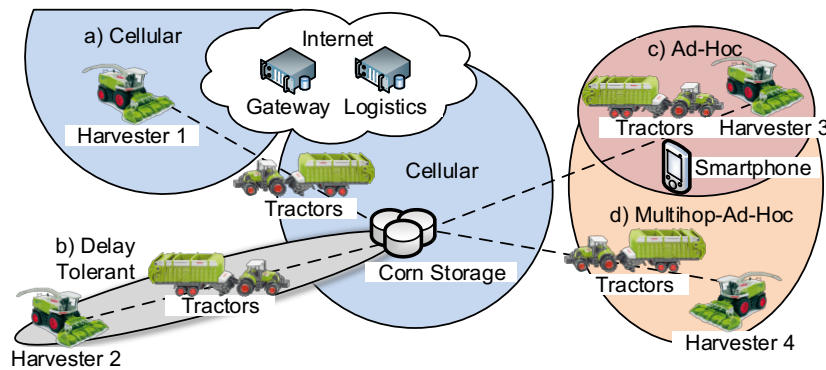

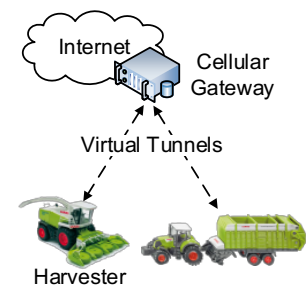Fig. 1: Robust communication in a harvest scenario   Fig. 2: Cellular Gateway

2.1 Cellular Communication Gateway

Cellular-based networks provide excellent communication possibilities to mobile nodes. The ongoing development of standards results in growing data transfer capacities of more than 100 Mbit/s and low delay times of less than 20 ms with LTE-Advanced. However, due to the mobility of nodes in rural areas, network coverage is often only available for some nodes. Others may feature network coverage, but weak signal strength or older standards (EDGE, HSPA) result in longer delays, lower network bandwidth or transmission errors.

KOMOBAR and ISOCom introduced a cellular communication gateway (cf. Fig. 2) to optimize communication with mobile nodes in cellular networks. The gateway is represented by a centrally located server, spanning a Virtual Private Network (VPN) across all mobile nodes. The nodes establish virtual tunnels to the gateway whenever network coverage is available. Routing between mobile nodes or internet-based communication partners is realized by the central gateway. Furthermore, the gateway is capable of adding delay tolerant data transfers by temporally storing data packets for currently not available nodes. Delivery is postponed until the destination node (re-)establishes its virtual tunnel. As a positive side-effect, VPNs allow to data compression prior to transfer and encryption of virtual tunnels to securely transmit data in non-secured environments.

2.2 Ad Hoc Communication

Ad hoc communication can be used whenever two or more mobile nodes meet (cf. Fig. 1). Discovery of neighbour nodes is done by specialized routing protocols, which also allow to transmit data using a communication path with intermediate nodes (hops).

Basically two types of routing schemes exit: Proactive algorithms like DSDV and OLSR frequently transmit hello beacons to be picked up by neighbour nodes. In contrast, reactive routing algorithms like DSR and AODV discover neighbours with beacon broadcasts at data transfer time. Both concepts are a trade-off between neighbour discovery time and network overhead produced by beacons [3].

Simulations and practical tests in KOMOBAR and ISOCom showed advantages for proactive routing algorithms. Due to periodic beacons, neighbour nodes are discovered rapidly. Reactive algorithms loose valuable transfer time by late neighbour discovery. The network overhead was minimal and can be neglected.

2.3 Delay Tolerant Communication

A continuous communication path between source and destination of a data transfer is assumed in traditional networks. However, commination paths in agricultural processes are intermittent and constantly changing due to the moving nodes spread across rural environments. Data transfer are prone to failures.

Delay Tolerant Networks (DTNs) are capable of transferring data even if no continuous path between source and destination exists. This is realized by applying the concept of Store-Carry-Forward (SCF) during transfer of data [4]. Data packets are stored at a node, carried until a new node enters communication range and forwarded until the destination is reached (cf. Fig. 3). It's important to note that DTNs multiply the chances for data transfers without given a guarantee for successful delivery.

Since the well-known TCP/IP protocol stack is not designed for intermittent connectivity, a new layer is introduced by the Bundle Protocol (BP) [5]. Located between application and network layer, the bundle layer encapsulates application data and initiates the transfer to the next hop using TCP or UDP.

Fig. 3: Store-Carry-Forward Communication

A main challenge in DTNs is the routing of data packets across an intermittent and dynamically changing environment with (partially) unknown node mobility. Many DTN routing algorithms create copies of data packets to distribute them within the network. In an optimal scenario this results in increased delivery ratios and low latency times. In non-optimal scenarios packet copies can quickly overload the network and worsen the delivery ratio.

Widely-used in DTNs is the Epidemic routing algorithm [6], which creates and distributes packet copies of to every node encountered. The algorithm is especially useful in scenarios featuring unknown / changing node mobility. Limitation of packet copies is done by Spray&Wait routing [6]. The Prophet [6] routing algorithm tries to utilize the node contact history by estimating chances for meeting neighbour nodes again. This saves network resources by avoiding packet copies, but takes time to identify future communication possibilities.

3. Configuration of Communication Platform

With three different communication techniques available, the concept of Always-Best-Connected (ABC) can be realized. ABC increases communication robustness by choosing and combining the best available techniques at every node along a communication path.

However, the best technique for the transfer of data packets cannot be identified in general. Error information of agricultural machinery is highly time-critical and essential data for managing agricultural processes. Process status information represents less time-critical data. Finally, log data is non-time-critical process information for documentation. It's worth spending more effort on transferring time-critical compared to less time-critical information.

As a basis, data was categorized into Class A (time-critical), Class B (normal) and Class C (non-time-critical). Especially for Class A data cellular networks should be chosen as preferred communication technique. If available, cellular communication features solid bandwidths and low latencies while reaching all communication partners at the same time. In contrast, Class C data may save resources and cost by transferring it using ad hoc and delay tolerant communication. If coverage is only partly available, time-critical Class A data needs to utilize every communication opportunity.

The hybrid network is supposed to transmit time-critical data fast and reliable while avoiding network overload situations. This conflicts with DTN routing algorithms, where no algorithm fits the needs of all data classes. Fig. 4 illustrates the problem case using a harvest scenario and the routing algorithms Epidemic and Prophet. Epidemic routing provides the highest delivery ratios for all data classes in Fig. 4 a). Delivery ratios decrease with growing network load, overload situations start at around 100 MB/h. Analysing the delivery ratios for

Class A data in Fig. 4 b), it becomes clear that Epidemic and Prophet are not able to transmit all time-critical data.

A solution for adequate packet handling is to allow every data class to specify its own routing algorithm. Agricultural scenarios with dynamic mobility can use Epidemic routing for Class A data while using Prophet routing for Class B and Class C data. The results of this configuration in Fig. 4 indicate that this performs well for all data, and especially good for time-critical Class A data. The network works well much longer due to saving network resources when transferring Class B and Class C data.

Another solution is to unbound algorithms from concrete data classes. In some scenarios every node may be in the ideal position to choose the appropriate routing algorithm itself. Monitoring and exchanging information about past communication statistics and opportunities (e.g. neighbour contacts) can support the choice of an algorithm.
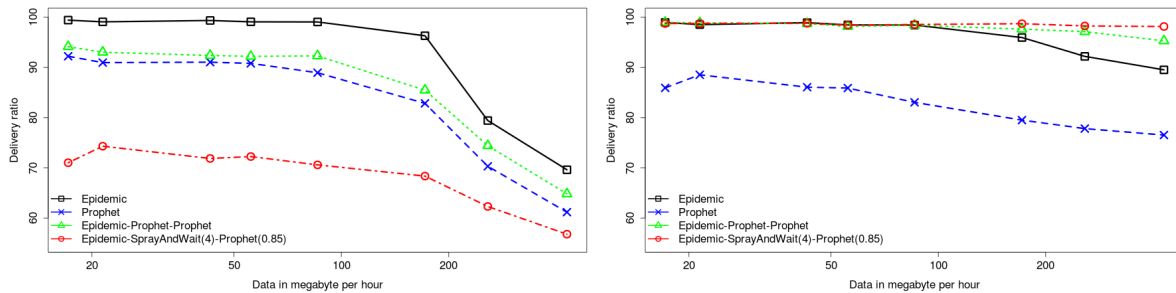

Fig. 4: Delivery ratios in harvest scenario for a) all data and b) time-critical data (Class A)

Dynamic reconfiguration of routing protocols during process runtime is essential for robust communication. For example, an optimal data packet lifetime represents the time a packet needs till it arrives at the destination. However, this depends heavily of the source and destination node as well as the current network situation. KOMOBAR introduced a mechanism for dynamic lifetime calculation. By monitoring past data transfers, an adjusted lifetime is configured for following transfers (see [7] for detailed information).

4. Testing of Communication Platform

The hybrid communication platform has been evaluated in OMNeT++ [8] simulations. Scenarios such as harvesting corn, potatoes, or cereals confirmed increased communication robustness. In addition, platform implementations for Linux, Android and iOS (partially) have been applied to real-world field tests. Ad hoc communication on Linux systems was realised using IEEE 802.11g hardware, running in ad-hoc-mode, and connected to external antennas. This resulted in ad hoc communication ranges up to 300 m. Fig. 5 shows pictures of a corn

harvest where harvester pipe images and the current position of tractors were displayed to the harvester driver.

Fig. 5: Field-testing ad hoc communication and cellular networking

5. Conclusion

Robustness of communication in rural areas can be increased by combining cellular networking and ad hoc communication in a delay tolerant way. Configuration of communication technologies is essential for optimal operation. On time delivery of time-critical data (e.g. machine error information) can be realized, even under challenging communication conditions and in heavily used networks.

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