Wireless Standards for Mobile Platform

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Abstract: The work deals with the problems of wireless communication in an autonomous mobile robots application. In the first part is given a definition of a cooperative exploration scenario for a group of mobile platforms and the requirements on the communication are evaluated. Then the overview of the applicable wireless standards WiFi, Bluetooth and ZigBee from the view of the application is given. Finally a solution using a Bluetooth mesh network is demonstrated in a simulation of the scenario.

Key-Words: wireless, mesh network, ad-hoc, mobile platforms

1 Introduction

The research in the area of mobile robotics has many directions and many successful areas. Different approaches to design and control these robots and groups of robots have been introduced over last years.

One of the directions is control of a cooperating group of mobile robots [1]. The cooperative behavior can bring significant benefits as more flexibility and robustness and may potentially be more effective than a specialized single robot approach.

For achieving a cooperative behavior within a group of mobile robots some kind of communication is essential, since the robots need to know about the others. Explicit communication enables message passing between robots using a communication channel. This information could include messages about the individual platform position and knowledge, messages concerning progress of a given task, messages for synchronizing, distributing the tasks and for maintaining the communication itself. The focus will be on a model exploration scenario, where the platforms cooperatively build or update a map of an unknown environment. The exploration is realized as a limited simulation model to present a framework for the communication protocol testing.

In this paper are used several terms from robotics that are often defined in different contexts. *Autonomous* robots are robots that make their decisions individually, they are not controlled by any other authority (central control or other robots).

A robot *behavior* can be defined as a component of a robot control system responsible for performing a particular action in a particular kind of context. This definition gives explanation of behavior from the robotics view. Here will be used a more simple view on behavior as "what the robot is doing in certain circumstances".

A robot *task* is a piece of work to be done by the robot to achieve an objective. The task can be a simple action or a composition of several actions.

A *mission* is the main task or objective of the group to be carried out. For example a mission can be to explore an environment, composed of several tasks such as path planning, environment mapping and obstacle avoidance.

Cooperation is such a purposeful behavior of multiple robots that results in a higher efficiency of completing the mission [1]. Cooperation is usually based on communication, since robots need to be aware of their actions.

Mission with its specifics (environment, number of robots, etc.) will be referred to as a *scenario*.

Communication between autonomous platforms has to deal with several specific issues. Firstly a high mobility should be expected, causing frequent link breakdowns and requiring topology changes, especially in indoor environments.

Several wireless communication standards have appeared and their applicability for the mobile platforms application is in question. The properties of Bluetooth, WiFi and ZigBee are evaluated from the application point of view. Results of a sample Bluetooth network simulation are summarized.

This paper introduces the model application - the exploration scenario in section 2 that is used to provide a framework for the communication described in section 3. The scenario together with the proposed communication is tested in a developed simulator presented in section 4. The Conclusion is given in the last section 5.

2 Exploration Scenario

The objective of an exploration scenario is to acquire a map of an environment. The map is a representation of the environment, it can be measurement of any quantity obtained by sensors. The task of the group is to move through the area and collect information. We assume that one scan of an area gives sufficient information and the area is considered as explored. The efficiency of the exploration then depends on the sharing of the information.

Exploration is necessary in many mobile robot missions, because the robots usually need to map the environment before they start the task or exploration is part of the task itself (search and rescue missions, pursuit-evasion games, foraging or surveillance scenarios [1]). Communication between the robots performing the exploration enables them to share the acquired information and enables them to cooperate and therefore to do the exploration more effectively.

2.1 Behavior Definition

The decisions are decentralized, based on a set of behaviors. Every robot has a local table for composition of the behaviors and deciding the next move. A positive value in the local table indicates a place to prefer and negative a place to avoid. Each behavior is modifying the cells around the robot position by adding "preferences", example is shown in Fig. 1.

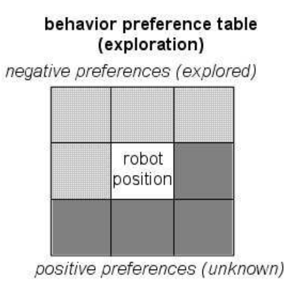

Fig. 1: Realization of a single behavior

After evaluation of all behaviors, the place with the highest positive value – the most "preferred" is selected as a next way-point the platform will go. If no value exceeds a certain limit the platform will move to a randomly selected place with a positive value.

The proposed behaviors are

- *obstacle avoidance*
  Is realized in a simple way, by setting negative values to the local table according to areas with a detected obstacle.
- *exploration*
  This behavior is trying to get the robot to the unexplored areas. The value corresponding to the last position is decreased to avoid going back on the same way if possible.
- *communicatio*n *maintaining*
  The robots try to keep connected. Only a basic interaction is proposed, the communication behavior increases preferences in directions that bring the robot closer to others.

The exploration and obstacle avoidance behaviors will try to keep the platforms far from each other. For this reason the communication maintaining behavior is employed, to keep the robots connected. The composition of the behaviors is shown in the figure 2.

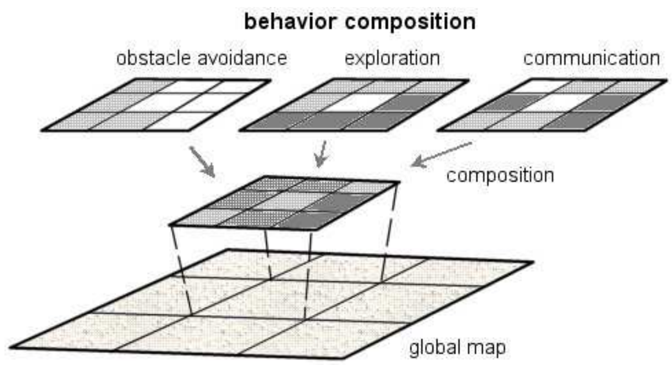

Fig. 2: The method of behavior composition

It is important to note that the behavior of the robots is not deterministic and does not guarantee successful completion of the task under all conditions. In simple environments this approach will work well and can be used to test the communication protocol. The resulting formation of the robot group is very loose and many of the robots will move on the limits of their communication range and eventually loose a link.

3 Communication

From the nature of the autonomous mobile robots system the expected communication requirements are mainly on distributed and autonomous operation. The most important property of the communication is considered the connectivity, as the functionality of the system (ability of cooperation) depends on communication.

A connected network can be realized in a number of ways, so other limitations should be put on the structure - the network topology. The communication must be reliable, the messages should have low latency and the network structure should be flexible. The network bandwidth is not considered as the key issue here, as the platforms are expected to exchange basic sensory data and control commands. The properties can be summarized in order of importance as follows:

1. *redundancy*
   The network should assure maintaining full connectivity if possible. Connectivity is the main claim on the network structure and therefore redundancy is required to provide reliable message delivery

2. *multi-hop network*
   The network must be in principle multi-hop to be able to provide communication over large or complex areas. The hop diameter of network is the maximum number of hops between any two nodes and should be kept low to reduce routing overhead and interferences. It was shown that for example for Bluetooth the interferences caused by too many piconets in one area can significantly decrease the network throughput (shown in [2]).

3. *minimal node degree*
   The degree of a node is the number of links or hops the node interconnects. The nodes with high degree become bottlenecks in the network and can severely reduce the network throughput.

4. *minimal transmission radius*
   In dynamic environments it can be important as the connections over shorter distances are more likely to last longer. Also it is expected that most of the information needs to be exchanged between devices close to each other.

The efficiency of a network topology depends on given requirements and circumstances, for some applications the network throughput is the most demanding, for others it can be reliability and robustness or the small rate of topological changes. From the number of the proposed topologies for wireless mobile networks seems the most suitable and now very popular mesh network. The mesh topology does not have any limitations on the structure and therefore is very flexible - mesh network can be build whenever a connection is possible (this will not be true for structured topologies - e.g. for a ring it is obvious).

3.1 Wireless standards

When thinking about wireless communication, three main candidates come into mind: WiFi (IEEE 802.11), Bluetooth (IEEE 802.15.1) and ZigBee (IEEE 802.15.4). WiFi provides user with the comfort of the IP stack and is easily set up. The Bluetooth is intended for low complexity and low power applications, which mobile platforms with embedded control certainly are. The ZigBee is a very new technology going beyond the Bluetooth and targets even more simple applications and provides lower power consumption and higher reliability.

3.1.1 WiFi

The WiFi (or Wireless LAN) is primary a single-hop network. But the network size is thanks to the use of the IP stack virtually unlimited. As it is a multiple-access network, all the nodes within range can hear each other and therefore within the single-hop is no need to worry about any topology. Problems arise when more networks (or hops) need to coexist. This will happen when the covered area needs to be extended, as in case of the exploration. The current solution is to use repeaters or a wired LAN to interconnect group of WiFi access points.

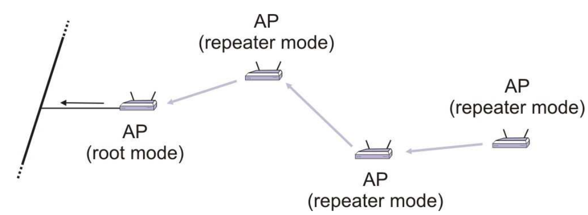

Fig. 3: Extending the range with classical WiFi

The help of such infrastructure ca not be expected in the exploration, as the area is unknown. The solution for such situations exist, it is the ad hoc mode (or peer-to-peer) extended with a routing protocol. The university in Santa Barbara, where the AODV protocol has been developed has released a user-space routing layer that enables building an ad-hoc multihop network on the WiFi.

The Ad-hoc On-demand Distance Vector (AODV - RFC 3561) routing protocol introduced in [4] is implemented to minimize the number of required broadcasts. It is an reactive protocol, where the path is discovered by broadcasting a route request packet. By implementing the protocol each of the nodes becomes an AODV router, forming and ad hoc mesh network.

3.1.2 Bluetooth

Bluetooth is a short range communication intended as a cable replacement in personal network applications. The basic Bluetooth network unit is a piconet, where is one master and up to seven active slaves. Each of the unit can become a bridge and interconnect more piconets to form a larger network referred to as scatternet.

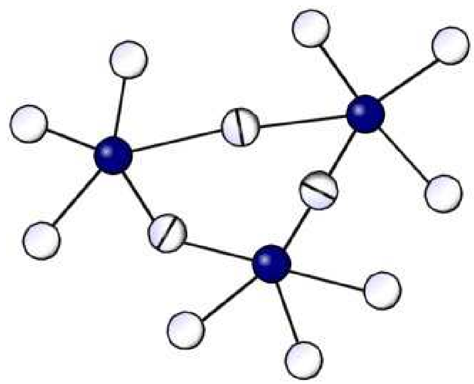

Fig. 4: Bluetooth scatternet

As no structure for the scatternet is defined, many proposed topologies have been proposed, including trees [5, 6], rings [7] or mesh topology as in [8]. Bluetooth is not intended for this purpose, but provides control over the networking and makes it possible to construct virtually any topology.

The biggest problem in Bluetooth ad hoc applications is the unit discovery. The Bluetooth does not support symmetric discovery protocol and this needs to be handled in the application layer. The performance of the unit discovery is key function in maintaining a connected network.

3.1.3 ZigBee

ZigBee is new standard targeting automation applications and provides the mesh functionality within the standard. The possible topologies for the ZigBee are mesh, star or cluster-tree, a hybrid combination of mesh and star. The devices in the ZigBee network are divided into full function devices (FFD) that can act as network coordinators or routers and reduced function devices (RFD) that can only act as end-devices.

The ZigBee provides self configuring network with healing abilities that is very flexible and easy to set up. The only problem may be in the reduced bandwidth, but it should not be a problem in the presented application.

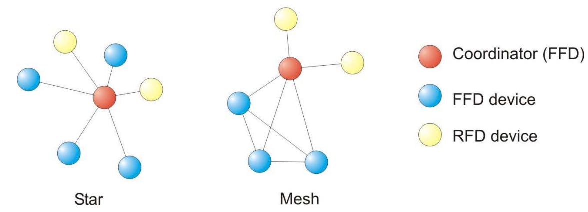

Fig. 5: ZigBee network topology

3.2 Summary

WiFi is suitable for applications where the whole area can be covered by a single network. It provides enough bandwidth for all applications and the communication can be easily programmed over the IP stack. The WiFi has from the mentioned standards the biggest computing requirements and the power consumption. This makes it applicable for platforms with an embedded PC and sufficient power source.

The Bluetooth is better suited for low power embedded applications and provides easy to use communication. It may be used in small devices with limited power and provide reliable communication. The problems with the use of Bluetooth in mobile application may arise because of short range and not very flexible networking options.

The youngest standard, the ZigBee is directly targeting automation applications. It provides reliable and secure communication and is ready for networking in complicated situations. From the listed technologies it has the lowest requirements on the system. It can be easily embedded into the smallest controllers and work over long periods using battery power. ZigBee has only a limited bandwidth capacity, what may be a problem in some mobile platform applications where for example a video signal may be transferred. Also the ZigBee is very new and there is not enough practical experience yet, but the results are promising.

A small table summarizing the main features of the described standards is given below.

Table 1: Comparison of WiFi, Bluetooth, ZigBee

	Throughput	Range	Stack	Power TX
WiFi	54Mbps	100m	100kB+	400 mA+
Bluetooth	1Mbps	~10m	100kB+	40 mA
ZigBee	250kbps	~30m	28kB	30 mA

4 Scenario Simulation

This section describes examination of Bluetooth mesh networking possibilities. A Bluetooth protocol that builds a mesh network has been proposed. To meet the listed requirements, the protocol is rule based. The base network structure is maintained by “connectivity rules” that assure a connected network, applying the principle described in [3]. The principle is based on the simple idea that if every node is able to reach all the nodes within its range, then all the nodes are in the network can be reached. The nodes within the radio range discovered by the Bluetooth inquiry/inquiry-scan are denoted as visible nodes and the nodes that can be reached over the network as reachable nodes. Every node discovers the nodes within range and if an unreachable node is found, it tries to connect to it.

Because the connectivity rules provide only limited control of the resulting network properties, another set of rules to adapt the network is implemented. The rules are implemented to minimize the number of piconets, avoid multiple bridges and reduce long links.

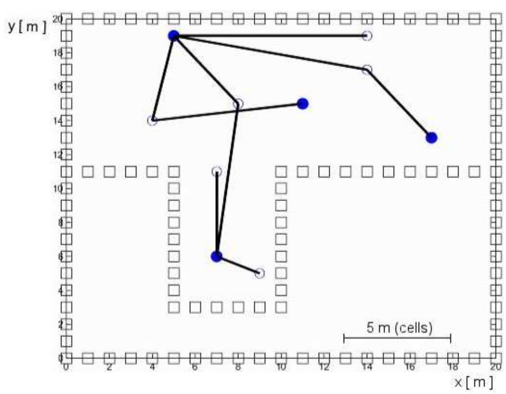

Fig. 6: Connected network without optimizations

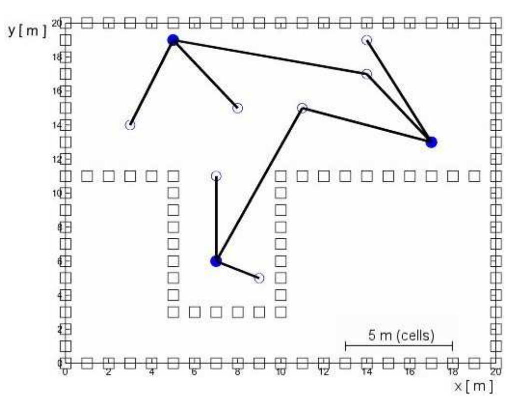

Fig. 7: Network optimized by the rules

The communication simulation is embedded into the described exploration scenario simulation. The exploration scenario is implemented as a simulation in a discrete-event simulation. The simulation uses a simple grid-based representation of the “real world” and the movement of the robots is evaluated in turns.

A platform is able to move from one cell to another in one round. Between the rounds, platforms evaluate the behaviors. First, the local decision table is set to zeroes, then preferences from the behaviors are added. Only eight cells around the robot are evaluated. Figure 8 shows an example run with three robots in a simple environment.

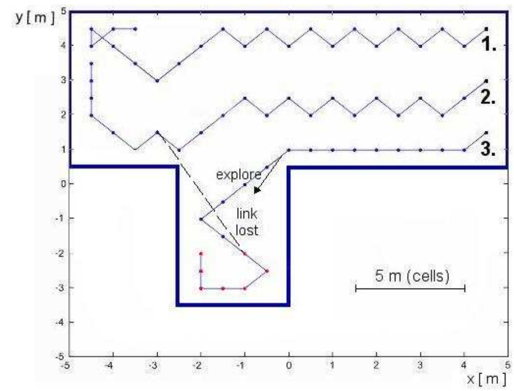

Fig. 8: Example of an exploration simulation run showing the paths of three robots during the exploration

The platforms start in the numbered positions in the simulated environment. They are attracted to the unexplored area, and proceed through the room. The platform 3 is pulled by the exploration to the open area what causes its communication link break and the group splits. The communication behavior can not prevent the situation of breaking line when the robots go behind a corner.

The communication simulation is inserted into the scenario simulator. The purpose of the simulation is to provide a tool for testing of the proposed protocol. The simulation uses ideal models of unit discovery, polling and scheduling (in means that they take the minimal possible time in the simulation).

The simulation is done in a discrete time steps, where the simulation cycles are inserted into the platform movement cycle. The simulation is done on the level of the Bluetooth baseband packets. In each cycle, one node is able to transmit and receive a packet on all of its links. Then the length of the cycle must be chosen long enough, because the problems of polling, bridge scheduling and the Bluetooth power saving modes are not covered by this model. The simulation cycle of the communication is chosen 20 times per one robot move cycle, which is 10 s.

The simulations have shown that the Bluetooth is able to provide a connected network, based on the mesh structure, in a highly mobile environment. The results showing the numbers of created and dropped links for different number of the platforms is shown in Figure .

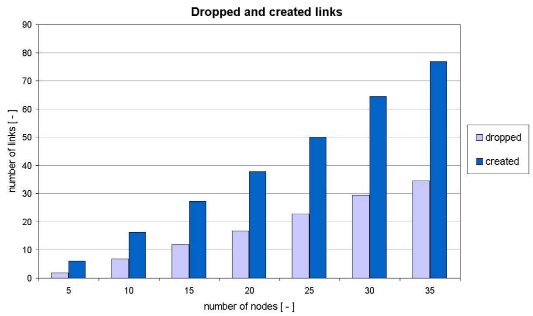

Fig. 9: Created and dropped packets by the protocol during the network set up.

The number of dropped links is less than one half of all the links created. The dropped links are the unnecessary or unsuitable links that are canceled by the optimizing rules.

5 Conclusion

The paper presented a model situation of a cooperative exploration as a framework for mobile wireless communication testing. The characteristics of the scenario have been presented and the resulting requirements on the communication have been discussed. The wireless communication standards commonly used in the automation, the WiFi, Bluetooth and the emerging standard ZigBee have been examined for their applicability in the proposed application.

A sample network protocol building a Bluetooth mesh network has been evaluated using a simulation of the scenario and the results were presented. Although the Bluetooth has shown the ability to handle the application, it is not the situation the Bluetooth is intended for and for example ZigBee seems more prepared to handle similar situations, as it has the mesh networking as its base feature.

The Wireless LAN is the winner in the situations were a higher bandwidth is required. It is also very efficient in situations where only single-hop network is sufficient, as it is very easy to set up. The ZigBee is targeting applications where reliable operation is in focus and provides options for flexible network structuring and is perfect for embedded applications where power consumption is an issue.

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