A Concept for Radio Standard Spanning Communication in Mobile Ad Hoc Networks

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***Abstract*— An important aspect in the field of self-organisation in mobile Ad Hoc networks is an efficient cross-linking of all nodes in a high-dynamic network topology. This should be durable against disturbances and partial losses and distribute the net load on all net elements as evenly as possible. Past research approaches limit their solutions to the usage of a homogeneous topology on basis of a unique radio standard. This paper deals with an approach for a communication in mobile Ad Hoc networks, that integrates multiple radio standards. Thereby, the choice of the used radio standard is invisible for the respective application. For the protocol conversion on the hardware side a special interface block is used. Thus enables an economical, radio standard spanning point-to-point communication on basis of the TCP/IP protocol stack. Furthermore, the concept offers the possibility of integrating already existing devices with standardised radio modules into an existing network topology.**

I. Introduction

With the introduction of portable communications devices - such as mobile phones or PDAs - new radio standards for a wireless information exchange developed [1]. A cross-linking of such devices to network topologies without a static infrastructure is called a *Mobile Ad Hoc network* (MANET).As a consequence of the constantly changing infrastructures, possibilities were looked for to transfer data stable and efficiently also in dynamic nets [2].

Due to different application areas of wireless communication networks in industrial and private surrounding fields, a multiplicity of radio standards was developed. These standards have optimised their characteristics in regard to transmission range, data transfer rate, power consumption and the used frequency band for the respective application. The current approaches for connectivity and communication in wireless mobile Ad Hoc Networks are however only occupied with one standard each. The radio standard spanning interaction is not possible.

This paper presents such an approach for the efficient interoperability of different radio standards and is divided as follows. Section II first gives an overview of past publications in the fields of topology optimisation and routing in MANETs, software defined radio (SDR) and interface synthesis. A new approach for radio standard spanning communication in mobile Ad Hoc networks is introduced in section III. Central problems are self-organisation, synthesis on the hardware side of incompatible interfaces and routing. Finally section IV gives a outlook for the future work in this research area.

II. Related Work

Self-organising mobile Ad Hoc networks offer many approaches for optimisations. A central point is the reduction of the power consumption by adjusting the transmitting power ([3][4][5]). Based on a dynamically optimised topology, data between arbitrary nodes can be transmitted in the network. For the efficient package-oriented data communication routing algorithms are used, which lead the packets over a preferably optimised path to the destination node ([6][7][8]). The presented approaches for the topology optimisation work within the Medium Access Control (MAC) layer of the OSI reference model. Routing algorithms, that route packets between arbitrary network nodes on the network layer are applied. If isolated network areas exist due to incompatible radio standards, then a communication is not possible. None of the approaches introduced here offers possibilities of solving communication problems in terms of incompatible radio standards.

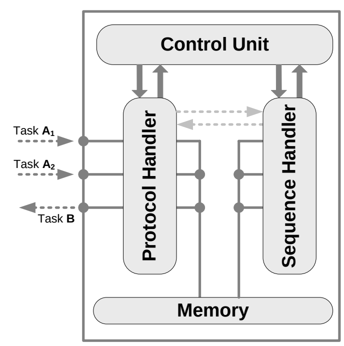

Fig. 1. The Interface Block (IFB) Macrostructure with three main components - Control Unit (top), Protocol Handler (left) and Sequence Handler(right). Two Tasks A (with the subtasks A_1 and A_2) and B with incompatible protocols communicate with each other using a IFB.

To provide the possibility of an integration of several radio standards into one heterogeneous network topology, a few approaches have been published. One basic idea is offered by Software Defined Radio (SDR [9][10][11]). Hereby, a majority of signal processing is accomplished by software modules and programmable digital hardware. Thus received data can be converted to other protocols in real time and then can be passed on. Already existing SDR systems can be extended by new communication standards by the modular structure at relatively little expenditure. An approach that is particularly engaged with a SDR based point to point communication, is to be found in point [12]. The possibility of integrating already existing hardware with standardised radio modules into a topology, which is based on SDR, is given in principle. Within the range of wireless communication, by this technology basis stations can be extended fast and economically by new modules. By the usage of multiple signal processors and software modules, a very high arithmetic performance and a large hardware complexity of an individual node is necessary, which impedes the usage of SDR in small mobile devices with limited energy resources.

A promising possibility for a radio standard independent communication is the hardware-near coupling of individual standardised radio modules. For this purpose a special block, which provides a communication of incompatible protocols, is necessary [13][14]. Such an interface block (IFB [15]) analyses incoming packets and extracts the user data. Subsequently, these data are adapted on desired protocols and passed on accordingly (*Figure 1*). Due to the IFB macro structure a modular expandability is ensured. With an increasing number of connected tasks, however, the IFB represents the bottleneck for communication. On further details is dwelled on in section III.

III. Concept for Radio Standard Independent Communication

In the following section a concept, which enables a radio standard spanning communication in mobile Ad Hoc networks is presented. Now the individual nodes of a network topology can use advantages of different radio standards to get higher degree of connectivity. They do not need a high arithmetic performance like it is necessary in the already mentioned research approaches of software defined radio. An energy-efficient and multifunctional applicable possibility of wireless communication is created. The presented approach is divided into three problem areas, which have to be solved:

A. Self-Organisation / Topology Construction

A basis for each communication is a mobiles Ad Hoc network with bidirectional links between individual elements. The structure and the care of the topology should be self-organised. So no central control instances are allowed and the topology creation and maintenance has to be organised decentrally by each node itself. The creation of a network topology takes place on the Media Access Control layer and is not visible for the application. A classification in the area of the self-organisation in mobile Ad Hoc networks is to be found in [16][17].

B. Protocol conversion

For the conversion of radio standard spanning communication, commercial and already standardised radio modules are connected on a hardware near layer. Thereby, the substantial problem is represented by the control of the individual radio modules. The respective communication protocol stacks on the modules are complex and partly realised in hardware and partly in software by appropriate drivers. Now possibilities have to be found for using radio modules of different standards and with different control mechanisms on one level. Therefore, an Interface Block (IFB), already presented in section II, can be used. Such an IFB represents the connector of the individual radio modules. Incoming packets are analysed and processed accordingly. In order to ensure the validity of the concept for a multiplicity of current radio standards, the IFB must provide a uniform protocol for all applications. By the usage of the TCP/IP protocol stack a platform-independent employment is ensured. In order to be able to administer extracted routing information from the IP packages, an internal extended routing table must be realised. Based on these routing information, the Link Controller Unit (LCU) chooses the physical interface, which will be used to route each data packet to its destination node. Therefore, the IFB extracts the user data, adapts it to the chosen radio module and initialises the data transmission.

Furthermore, for the individual radio modules a topology control has to be provided, since depending upon radio standard different linking strategies are expedient. On basis of the integrated topology control, the IFB manages the packet adaption and forwarding over the several radio modules. The choice of the used physical interface is not visible for software applications. For communicating these applications use only one defined interface, which is provided by the IFB. On IP level this interface represents the standard gateway.

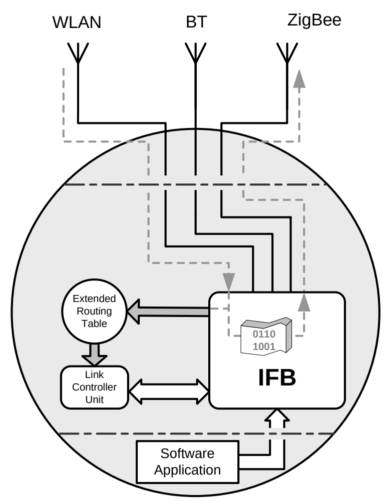

Fig. 2. Basic layout of a radio standard independent node. Exemplary with three antennas for the radio standards Wireless LAN, Bluetooth (BT) and ZigBee at the top of the picture. In the center the hardware block, called IFB, for connecting the radio modules. Routing information stored in an extended routing table on the left side. Based on these routing information, the link controller unit (LCU) manages the data flow in the IFB. Software applications with only one well-defined interface to the hardware block.

By the realised interoperability of several radio standards, an integration of conventional communications devices (mobile phones, notebooks, etc.) with standardised radio adapters into an existing network is possible. Therefore, a condition is an already existing network topology with a sufficiently number of nodes, which can function as radio standard spanning gateways. In addition software applications of the devices must be able to transmit their user data per TCP/IP over the available network interfaces. Nodes in range, which have the possibility of connecting several radio standards, enable a point-to-point communication on demand.

Figure 2 shows the conceptional structure of such a node. The representation shows a system with three available radio standards. The concept permits a modular extension of additional interfaces. At an increasing number of integrated radio modules, the connecting IFB represents a bottleneck regarding the data transfer rate, since all packets must be analysed and processed here. The administration complexity rises accordingly and there is an increased arithmetic performance necessary in the nodes, which affects energy resources negatively. The maximum data transfer rate and the maximum bandwidth of the connecting interface block limit the number of integrated radio standards upwards. An exceeding of the limit increase latencies and would interfere the communication in the network. Depending on the used radio standards, the maximum transfer rate is reached with a different number of modules in each node. For example, the necessary IFB data transfer rate R_{total} of the represented node in *Figure 2* with three available radio modules is calculated as follows (α represents an additional correction factor):

$$\begin{aligned} R_{BT} &= R_1 = 2.1 Mbit/s \text{ (Bluetooth 2.0+EDR)} \\ R_{WLAN} &= R_2 = 54 Mbit/s \text{ (IEEE 802.11g)} \\ R_{ZigBee} &= R_3 = 0.25 Mbit/s \text{ (IEEE 802.15.4)} \\ R_{total} &= (\sum_{i=1}^{3} R_i) + \alpha \\ R_{total} &= 56.35 Mbit/s + \alpha \\ R_{IFB\ intern} &\geq 56.35 Mbit/s \end{aligned}$$

C. Routing / Forwarding

In order to realise a network based on point-to-point communication, a suitable routing method with small latencies and a minimum number of hops per route path must be available [15]. In combination with the problem subsection A (Self-Organisation / Topology Construction) the routing algorithm is crucial for an adaptive, scalable and efficient communication in the network. By the usage of the TCP/IP protocol stack, well-known routing strategies can be implemented. Further, a platform-independent usage is possible, since the TCP/IP is enabled in almost any system.

For the primary usage in applications of mobile miniature devices, which have strongly limited energy resources and usually small arithmetic performance, the choice of the routing algorithm is of great importance. In order to minimise the hardware complexity for storage and administration of routing information in the devices, a reactive routing (see section *II*) has been implemented. The selected routing method is able to make decisions about the choice of the used radio standards on the basis of functional connection requirements, for example necessary bandwidth or available energy resources. The decisions are made on basis of dynamic cost vectors, which calculates their values on basis of predefined weighting parameters like basic power consumption, transmitting power or costs for data conversion.

Example

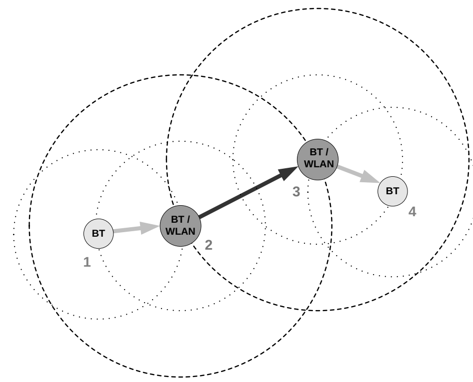

Fig. 3. Example 1: Communication between two Bluetooth Nodes using two additional Nodes with an separate Wireless LAN Interface

Figure 3 illustrates the presented concept. You can see four mobile communications devices. The two nodes 1 (left side) and 4 (right side) represent simple communication devices with a standardised Bluetooth interface. Now a data exchange between the two nodes 1 and 4 will be initiated. This requires software applications, which works on basis of the TCP/IP protocol stack and have the possibility to send data packets over the available Bluetooth interface. Further, applications have knowledge about the own IP address and the IP addresses of the connecting partner and the nodes within transmission range.

With the attempt to establish a connection, node 1 notices that node 4 is not reachable, because it is outside of node 1s maximum transmission range. Now the device could try to broadcast the IP packet, whereby a significant net load would be generated. Alternatively the node transmit the packet to one reachable node, which is determined with the help of the used routing strategy. In this given example, the inquiry receives node 2 in any case, which has two wireless network interfaces for WLAN and Bluetooth. After the packet has arrived in node 2, it passes different hardware layers and finally reaches in the already presented Interface Block. Here the packet headers are extracted and analysed whether the IP address fits to the own system. Node 2 notices that the arrived packet is not intended for its system. Now it updates the header information of the packet and prepares it for forwarding. Therefor the defined routing method is used once again. In addition information needed for a correct path back to the starting node must be stored internally. In the represented example a conversion of the communication protocol in node 2 is required. The Interface Block packs the IP data in a Ethernet packet and transmits it over the WLAN adapter. For the software applications this procedure is not visible. After the packet arrived via WLAN into node 3, it is processed similar to node 2. The Interface Block examines the extracted header information again and compares the IP data with the data of the own system. Because no matches were found, the packet may not be passed to the upper application layer. Now the IFB looks in the internal extended routing table for relevant entries. Here it finds a match for the destination IP address of node 4 with all available interfaces. A second protocol conversion. After all necessary package information was extracted and stored, the ethernet frame can be rejected and the IP package can be packed into the Bluetooth protocol stack. The user data now arrive over the established Bluetooth connection to the destination node 4. With the stored packet information in the gateway nodes, data on the way back from node 4 to node 1 can be processed accordingly faster. *Figure 4* clarifies the data flow in a radio standard spanning network.

In the presented concept the used routing algorithm is a free selectable parameter. So there is no limitation of the quantity of possible solutions. In order to limit the protocol overhead in the network, a route cache in each node is realised. Used route paths receive a maximum validity period. If the destination node on the stored route is no longer attainable or the validity period of the route ran off, the search for a valid route path is repeated with the help of the selected routing strategy. Thus the use of actual and optimal routes in the network is ensured. An analysis about validity period of routes in Multihop Mobile Ad Hoc Network is to be found under [18].

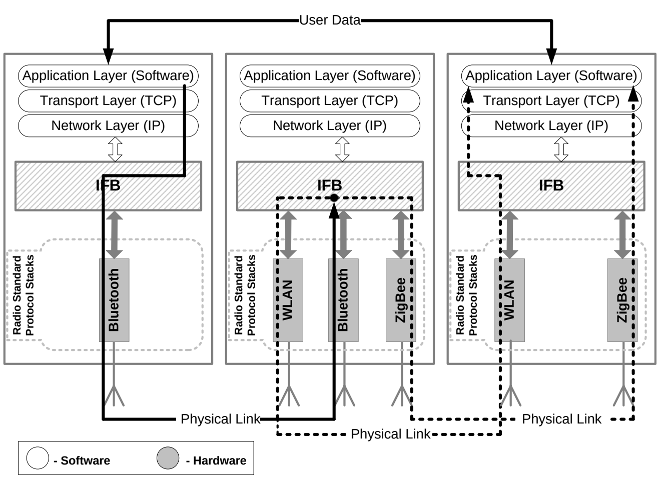

Fig. 4. Example 2: Logical and physical data path during a radio standard independent point-to-point communication. The IFB interconnect the wireless interfaces on the network layer. Software applications communicate over a separate IFB Interface

IV. Continuous Work

The resuming work examines open points of detail and concretises the presented concept. Initially, a special simulation environment for mobile Ad Hoc networks is to be implemented, which is able to visualise different routing strategies in radio standard spanning network topologies. The statistic results are consulted for an optimal choice of the used routing strategy. In this context, already existing solutions regarding robustness, scalability or protocol overhead are supposed to be compared further on. In order to realise a cost function for the intelligent choice of the used interfaces, selected approaches must be modified or extended accordingly. Further works concentrate on the analysis of available hardware components and their suitability regarding the concept presented here. Suitable routing strategies for the presented concept must be analysed and evaluated. the choice of the used interfaces on basis of suitable cost vectors represents a central challenge. In parallel with that, first hardware implementations shall be initiated for already analysing fundamental problems in this early phase of developments.

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