SOFTWARE DEFINED PROTOCOLS BASED ON GENERIC PROTOCOL FUNCTIONS FOR WIRED AND WIRELESS NETWORKS

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ABSTRACT

This paper introduces an efficient and flexible approach for the design and implementation of communication protocols for wired and wireless networks, enabling an adaptive and reusable protocol stack realization. For the design and specification of new communication protocols suitability proven components are often reused and extended to meet system specific demands. So, wireless protocols share a common origin with wired protocols as exemplarily shown for the LAPD, $LAPD_m$ and LAPC data link control protocols. To enable the vision of a smooth integration of the fixed and the mobile world a protocol design based on a generic protocol stack is proposed. The considered protocols are grouped into a system specific and a common part. The system specific part implies the distinctive characteristics of the considered network technologies while the common part builds up the generic protocol stack that is based on the generic protocol functions of different networks. The specific parts either of a wired or a wireless system form together with the generic stack a multi-mode protocol stack that is highly adaptive to any type of communication network.

1. INTRODUCTION

The protocol design and development of wired and especially wireless networks is a complex and therefore challenging issue. A potential multi-mode protocol would shorten the developing process of communication protocols. The design and implementation is enhanced, enabling a faster evaluation, analysis and simulation of the protocols compared to conventional approaches. This paper introduces and deepens the concept of a generic protocol stack [1] based on the design of generic and adaptive protocol software (DGAPS) [2] in the context of wired and wireless networks. The common understanding of protocol design assumes a layered structure of network protocols leading to a protocol stack. This paper focuses on the data link layer of (1.) ISDN, a wired digital network, (2.) GSM/GPRS, a cellular radio network technology, and (3.) DECT, a cordless telecommunication system for the home environment.

The subsequent Section 2 starts by giving a short historical overview on the protocol design for wired as well as wireless networks. Due to the dedicated constraints of the air-interface wireless communication protocols are much more sophisticated than protocols for wired technologies. Thus, the main challenges of protocol design are introduced under consideration of the distinctive characteristics of wired and wireless networks. Section 3 shows the evolution from wired to wireless networks at the example of the *Link Access Procedure on the D-channel* (LAPD) of the ISDN standard. This data link control protocol is used in wired ISDN, also referred to as N-ISDN, and B-ISDN as well as lightly modified in the wireless standards GSM/GPRS, there referred to as $LAPD_m$, and DECT, there named LAPC. Section 4 proposes a generic protocol stack as a common basis of these in the past departing wired and wireless protocols resulting into an efficient and flexible Multi-Mode Terminal, see Figure 1. Additionally, a generic frame structure, which may be used in the data link layer of the generic protocol stack, is introduced to illustrate the proposed approach. The implementation of this generic protocol stack is presented in Section 5, while Section 6 addresses the arising research issues in the context of a multi-mode capable protocol stack. Its realization and exploitation is concretized in Section 7. Finally this paper ends with a summary and conclusion in Section 8.

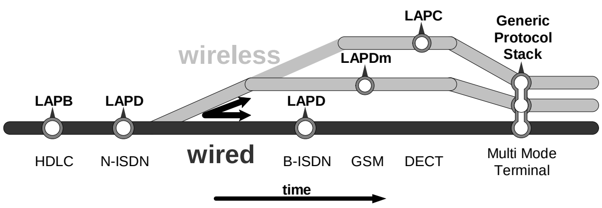

Figure 1: Generic protocol stack as a common basis for wired/ wireless networks considering HDLC-based signaling protocols as example.

2. PROTOCOL DESIGN FOR WIRED AND WIRELESS NETWORKS

2.1. Historical Context of Networking

Traditionally, the focus on protocol design yielded on wired and fixed system installations. Leading roles in networking were overtaken by the military and civil research institutions. While deployments in the very beginning still targeted on local interworking, the need for a ubiquitous allembracing facility for data transfer emerged. Based on those challenges, initial projects like the Advanced Research Projects Agency Network (ARPANET), a predecessor of today's Internet, aimed at the interconnection of military hosts. Later, also civilian research laboratories joined. With the upcoming evolution of high-power and low priced hardware more and more system installations became available. However, due to the application of non-standardized proprietary installations, local networks resembling wired connected island-solutions developed. Recognizing the need for a global framework for interconnection of differently structured networks, the International Standardization Organization (ISO) worked on a reference model to achieve interconnection of arbitrary open systems. This so called ISO/OSI reference model [3] provided the necessary context for the subsequent development of further communication systems, both wired and wireless.

In addition to the provided framework and infrastructure, the development of ubiquitously applicable protocols was the second important precondition to enable proper networking. A milestone in the design of protocol development was the introduction of the Internet Protocol IPv4 in 1981 from which today's commonly known connection of different networks, the Internet, derived its name. Together with the Transmission Control Protocol (TCP) the underlying protocol family for the interconnection of different kind of hosts in the Internet was born.

2.2. Properties of Wired and Wireless Networks

With the help of the ISO/OSI reference model and its encompassing 7 layers, it is possible to abstractly describe functionality. This description considers a capsulation applying the service provider service user model. Higher layers utilize lower layer services without having detailed knowledge on the respective realization, which is an important fact since this allows the application of the model to both wired and wireless standards. As a consequence, basically any application may be run regardless whether the applied transmission medium is a physical connection or the air-interface.

Whereas the upper layers 4-7 are also referred to as network independent, the lower network dependent layers 1 and 2 clearly need to consider dedicated system aspects. Layer 3 is commonly seen as the link between the network dependent and network independent layers. From the protocol engineering point of view this means, that very specific challenges and properties need to be overcome, here introduced in the following for layer 2.

2.3. Main Challenges of Protocol Design for the Data Link Layer

The tasks of the data link layer (= layer 2) actually are divided into two parts, which are medium access and logical link control. Both services aim on providing a secure and reliable data transmission of layer 3 protocol data units (L3-PDUs) by applying services of the physical layer. For the transmission of L3-PDUs, usually segmentation in smaller transmission units is performed. Depending on the reliability of the physical link, longer (wired networks) or shorter (wireless networks) units are segmented. Further on, layer 2 introduces further systematic redundancy to achieve optimized error detection or correction feasibility depending on the transmission medium. Due to the incoherent nature of the radio channel, ARQ schemes as applied in wireless networks usually are more sophisticated than within fixed networks taking into account, that the feedback signaling also faces a not negligible chance of being interfered. For the medium access usually different schemes are applied in the fixed and the wireless world. Whereas Local Areas Network (LAN) protocols like Ethernet [4] apply a Carrier Sense Multiple Access with Collision Detection (CSMA/CD), a simultaneous transmission and reception however is not feasible in wireless networks. Therefore, wireless LANs like IEEE 802.11 [5] need to apply Collision Avoidance (CSMA/CA) strategies. Another important difference for layer 2 protocol design is the realization of synchronization. In fixed networks like the Ethernet, data transmission on the physical layer (= layer 1) complies with a single bit stream. It is the task of layer 2 to recognize respective data blocks by monitoring the stream and matching dedicated bit pattern indicating the beginning and the end of a block. Wireless layer 2 protocols as applied in GSM/GPRS however, achieve synchronization by the layer 1 inherent TDMA transmission scheme. Consequently, the additional overhead needed for pattern matching becomes obsolete.

3. DATA LINK LAYER PROTOCOLS FOR WIRED AND WIRELESS NETWORKS

The origin of specific wireless standardized protocols for wireless networks goes back to their wired networks counterparts. Since those algorithms had turned out to promise a stable operation, a rather evolutionary than revolutionary approach in the design of protocols for upcoming mobile systems was chosen. This reasons the application of well known features of the fixed world in the mobile world under consideration of certain adaptations.

The following subsections introduce exemplarily wired and wireless protocols of the data link layer as they are specified in the standards of ISDN, GSM/GPRS and DECT.

3.1. Signaling Protocol of the ISDN Data Link Layer

In the ISO/OSI model the data link layer is located above the physical layer. It is responsible for the secure transmission of data over individual links between two directly connected network elements (nodes) as well as for the error handling of data packets. More precisely, in ISDN these nodes are referred to as the subscriber and the network. The data link control protocol of the ISDN D-channel is called LAPD [6][7]. It is based on X.25/LAPB and the HDLC/ISO 3309/4335 protocols. The purpose of the LAPD protocol is to reliably transmit layer 3 user information via ISDN using the D-channel.

3.2. Signaling Protocol in the GSM/GPRS Data Link Layer [8]

The data link layer of GSM consists of one single layer and therefore it differs from the structure as introduced in Section 2.3. The GSM specifications with regard to the data link layer [9], [10] are oriented on the ISDN LAPD protocol. Some individual adaptations were made as for example, unlike the LAPD protocol, no limiting flags are required. The synchronization is already provided by layer 1, and because of the existence of several logical channels a special data link control protocol had to be specified. Analogously to ISDN, this protocol is called $LAPD_m$, where ‘m’ stands for mobile. It is used between MS and BS, whereas between BTS and BSC over the A_{bis} interface the LAPD protocol is used, as illustrated in Figure 2.

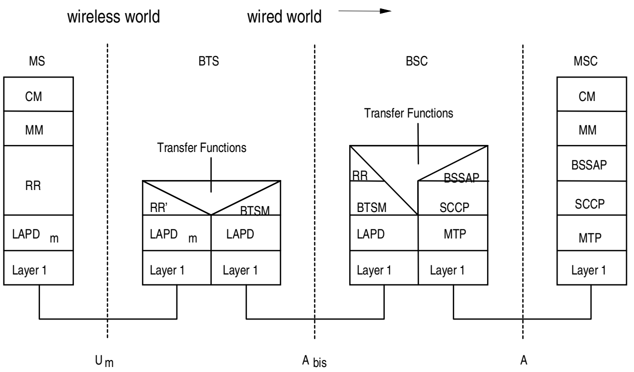

Figure 2: Architecture of the signaling protocols and distribution among GSM nodes

The communication protocols in the GSM system in some cases deviate from the ISO/OSI reference model. Although the protocols used in GSM can be structured on the basis of the ISO/OSI model, other protocol functions come into play because of the special characteristics of a cellular radio network. Therefore certain wide-ranging tasks, such as the evaluation and allocation of required capacity in a radio path and management-related services, do not necessarily only affect one particular ISO/OSI layer. These propositions count as well for the DECT standard which is introduced in the following subsection.

3.3. Signaling Protocol in the DECT Data Link Layer[8]

The DECT standard for cordless telecommunication separates the layer 2 into data link control and medium access as aforementioned in Section 2.3. A relative of the LAPD protocol is used for data link control in the DECT standard, there referred to as LAPC protocol [11]. Compared to LAPD some individual adaptations were made in the LAPC protocol. It differs to $LAPD_m$ of GSM in medium access control specific service primitives and protocol specific extensions to the frame structure of the protocol data units, see Section 4.2. These differences can be mainly explained with the differing structure of the data link layer and the dissimilar medium access.

From the aforementioned it becomes obvious that due to historic reasons and the framework provided by the ISO/OSI model, protocols of wired and wireless networks inherently feature by at least concordant roots, as it becomes observable for the LAPD, $LAPD_m$ and the LAPC protocols, illustrated in Figure 3 with the help of the Universal Modeling Language (UML). Regarding latest efforts in conceiving multi-mode protocols for wired/wireless networks, this commonality should be exploited to achieve convergence from the perspective of protocol design.

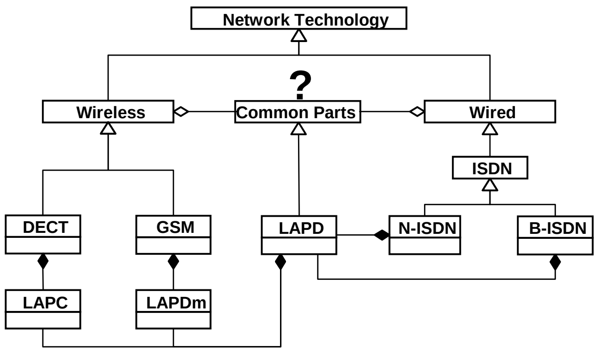

Figure 3: UML diagram for the derivation of a generic protocol stack for wired and wireless networks out of their common parts at the example of the LAPD protocol

The following section subsequently introduces a concept that benefits from this communality in the perspective of protocol design while taking into account distinctive characteristics of wired and wireless networks.

4. GENERIC PROTOCOL STACK FOR WIRED AND WIRELESS NETWORKS

4.1. Introduction to the Concept

To enable the vision of a smooth integration of the fixed and the mobile world a protocol design based on a generic protocol stack of generic functionality is proposed. This generic functionality is the incorporation of common parts of different wired and wireless networks. The envisaged realization of the generic protocol stack mainly targets layer 2 and 3 but may also consider the other layers of the ISO/OSI reference model.

Regarding the example as presented in Section III, there are two possibilities for implementing parts of a generic data link layer. On the one hand, an implementation of the LAPD protocol composed out of a generic and a system specific part or on the other hand, if the degree of genericity shall even be enhanced, a generic implementation of the LAPD protocol within the common parts, as indicated in Figure 3.

4.2. Approach for the Realization of a Generic Link Layer

In this section an approach to a generic link layer is introduced at the example of a generic frame structure for the protocol data units of this layer. An investigation of the frame structures of the data link control messages of ISDN, GSM/GPRS and DECT shows that all systems contain the following fields:

- an address field
- control field
- length indicator
- information field
- length fill field

The ISDN and DECT frames contain a checksum field of two octets in addition to the fields listed above. The listed fields, however, are not all useful for the generic frame structure, as they are in most cases of different length and structure. The frame structure of a generic message should contain the control field and the length indicator field as used in all standards, see [7], [10] and [11].

Figure 4 shows the difference between the address fields of ISDN, GSM/GPRS and DECT. In common, the address fields of ISDN and GSM can be extended to increase amount of available addresses. Thus, in the address fields bit ‘1’ is used as extended address field extension bit (EA) by ISDN and GSM to extend the address field range. Referring to the LAPD protocol of ISDN the EA bit has the value ‘1’ in the final octet of the address field. With respect to a further implementation of extended address fields in the DECT specification the reserved bit (RES) is always set to ‘1’. In this case the first bit is in the same way the final one. Thus, in the generic frame structure this bit can always be interpreted as specified in GSM. The command/response bit (C/R) is used in all standards to categorize a message as command or response. Although the Service Access Point Identifier (SAPI) is represented by three bits in GSM, it can be treated in the same way like in DECT, because it is only defined for the value 0 and 3. Contrary, the ISDN SAPI can contain a much larger number of values and allows 64 service access points to be identified. The Terminal Endpoint Identifier (TEI), the Logical Link Number (LLN) and the Link Protocol Discriminator (LPD) do not have anything in common. The same holds for the last bit, which is part of the TEI in ISDN and has no functionality in GSM, while it is used as New Link Flag (NLF) in DECT.

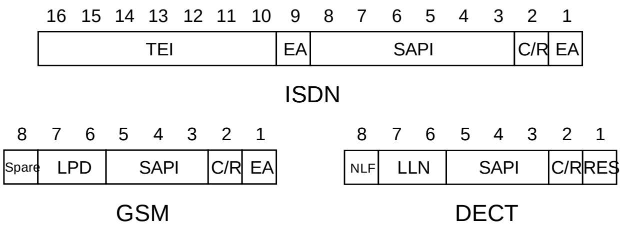

Figure 4: Address field formats of the LAPD, LAPD$_m$ and LAPC protocol

The generic data link control entity can also support an appropriate set of commands and responses, which may be used by both entities of the link for data transfer. These messages are directly derived from LAPD and therefore common to all the standards. The control field identifies the type of frame which will be either a command or response, see Table 1. Three types of control fields are specified: numbered information transfer (I format), supervisory functions (S format) and unnumbered information transfer (UI format). The structure and meaning of the different control field formats are shown in Table 1. Multiple frame operations are supported by the send sequence number N(S) and the receive sequence number N(R), which are part of the control field as shown in Table 1, too.

Table 1: Command and responses for generic L2 operations

Format	Commands	Responses	8 7 6 5 4 3 2	1
Information Transfer	I		N(S)	0
			N(R)	P
Supervisory	RR	RR	0 0 0 0 0 0 0	1
			N(R)	P/F
	RNR	RNR	0 0 0 0 0 1 0	1
			N(R)	P/F
	REJ	REJ	0 0 0 0 1 0 0	1
			N(R)	P/F
Unnumbered Information Transfer	SABME		0 1 1 P 1 1 1	1
		DM	0 0 0 F 1 1 1	1
	UI		0 0 0 P 0 0 1	1
	DISC		0 1 0 P 0 0 1	1
		UA	0 1 1 F 0 0 1	1

I:	Information
RR:	Receive Ready
RNR:	Receive Not Ready
REJ:	Reject
SABME:	Set Asynchronous Balanced Mode Extended
DM:	Disconnected Mode
UI:	Unnumbered Information
DISC:	DISConnect
UA:	Unnumbered Acknowledgement

5. IMPLEMENTATION OF THE GENERIC PROTOCOL STACK

The targeted realization is introduced in a refinement process of three steps. The basic idea, which is the origin of the envisaged approach, is introduced on the conceptual level, leading to a formal implementation. This abstract implementation level is concreted to point out the realization in software (concretion and realization level).

The conceptual level, as illustrated for the LAPD protocol family in Figure 3, incorporates the basic idea of Section 4. The concept implies a separation into a permanent resident part (the generic protocol stack) and add-on modules (the wired/wireless network specific supplements). The permanent resident part is derived from the common functionality of different standards. Having the ISO/OSI reference model in mind, as a common basis of these standards, a degree of similarity can be found. These common parts have to be identified, whereas the detail and their localization within the protocol stack is decisive for the success of this approach as these common parts are the generic basis for multi-mode protocols. In the case of too different stacks, the grade of genericity decreases and the protocol specific extensions become too dominating.

In the implementation level, the common parts are combined leading to a high degree of genericity and they are therefore referred to as a generic protocol stack, in Figure 5 simply named generic stack. The basic approach is to integrate this generic stack in a multi-mode stack together with the protocol specific parts, which again contain the differences between the considered original wired and wireless stacks. The specific parts include functions that are explicit to the respective standards and thus represent the individual behavior of a network. This is of a special advantage, if more than two systems are considered: Procedures which are common to most but not necessarily to all standards still will be implemented within the generic stack. The standard-specific supplements than will have to replace/overload the corresponding procedures.

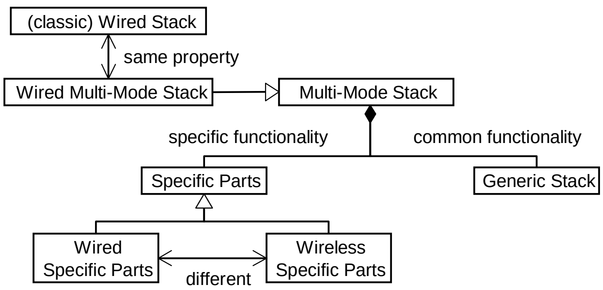

Figure 5: UML Diagram of a multi-mode protocol stack based on its composition out of a generic protocol stack and system specific parts

In particular, the multi-mode protocol stack becomes system specific by means of derivation. The common generic protocol stack is merged with the system related subset of the specific parts ending up in a system specific multi-mode protocol stack which has the same property as a classic protocol stack of the original wired/wireless system.

The approach on UML basis of Figure 5 leads to a clear implementation in the sense of a protocol specification in SDL and C++ as introduced in Section 7.

In making use of shared resources the multi-mode protocol stack based on a generic stack supports efficiency and flexibility at the same time. The generic specification of the layer functions enables a convergence of supported wired and wireless offered services. While using a specific service in one type of network (e.g. wireless), a mapping of this service to be overtaken and continued in the other type (e.g. wired) is envisaged by transferring the layer specific protocol state machine context of one system to another. This mapping is only facilitated due to the common basis of the generic stack. Consequently a communication session can 'survive' the switching procedure without disruption: a seamless reconfiguration hidden to the offered services is performed.

6. RESEARCH ISSUES IN THE CONTEXT OF A MULTI-MODE PROTOCOL STACK

There are a number of direct related research issues to be addressed in the context of designing a multi-mode protocol stack for wired and wireless networks as illustrated in Figure 6, like

- the definition of elementary commonalities of the various wired/wireless communication systems,
- a framework to enable protocol reconfiguration,
- modular software design and interfaces,
- detailed structure of a generic protocol stack.

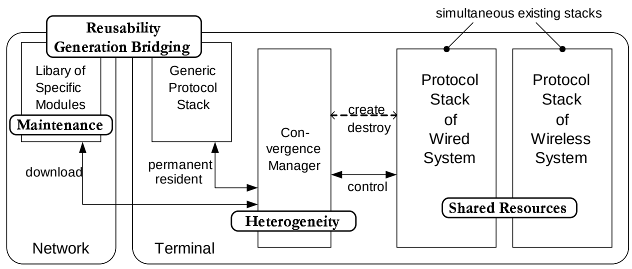

Figure 6: Overview of research issues in the context of a multi-mode protocol for wired and wireless networks

More advanced research issues can be identified based on a multi-mode protocol stack, like the

- composition of a multi-mode protocol stack architecture adaptable to the environment
- sharing of the terminal's resources within the telecommunication software (by means of power, memory, processor time, send/receive components etc.),
- reusability of software and generation bridging,
- maintenance of an existent system by software extensions.

7. REALIZATION AND EXPLOITATION OF THE MULTI-MODE PROTOCOL STACK

A top down approach is chosen to model the multi-mode protocol stack enabling an analysis of this stack and its extension to the used methods for realization. The top-down approach to the realization of a multi-mode protocol stack is depicted in Figure 7. The first two levels of concept and implementation are introduced above with the help of UML. During the process of modeling this UML implementation is replaced more precisely in a formal concretion ending in a realization of the multi-mode stack.

Therefore, this multi-mode protocol stack and the supporting framework are to be developed and specified with the help of the Specification and Description Language (SDL). SDL is an object oriented programming language which was standardized by the ITU-T and is based on the theory of extended infinite state machines. SDL can be considered as an intermediate step between specification and implementation in a higher programming language. Additionally, these higher programming languages, here C++, can be integrated into the SDL simulation environment for evaluation and complex mathematical operations due to detailed functionality.

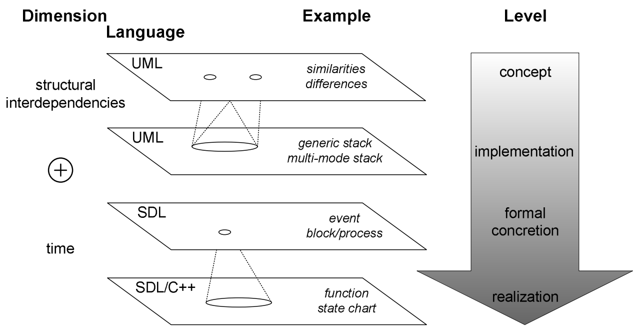

Figure 7: Top-down approach to modeling for an analysis of a multi-mode protocol stack and the used methods

This multi-mode protocol stack may enable a seamless communication during reconfiguration and simultaneous existing protocols for various traffic requirements.

Performance evaluations should address on the one hand the additional effort for the multi-mode capability of the protocol stack and on the other hand the time critical reconfiguration procedures themselves. Therefore, the multi-mode protocol stack needs to be compared to existing dedicated wired or wireless protocol stacks that do not follow the proposed separation into a generic and a system specific part.

Two complementary approaches are envisaged to realize the generic stack and its generic functionality. First an object oriented approach based on inheritance: It is suggested to implement the common parts as subclasses derived from base classes implemented within the generic stack. This advance can be referred to as a white-box approach, as the internals of parent classes are visible to the subclasses. The second approach is based on the functional composition of independent modules. These modules are adapted through parameterization to the targeted standard. A complete protocol stack is formed through a composition of parameterizable common modules and system specific modules. Such a composition requires well defined interfaces, while the internal details of a module are not visible. Therefore this advance can be compared to a black-box approach.

The base classes which are inherited together with the common modules can be terminal resident while system specific modules and subclasses are downloadable. Most promising for an efficient and clear implementation of the generic protocol stack might be a combination of both approaches depending on the functional level of the similarities. Common parts of the modules may be inherited while the protocol stack itself is strict modular. In this way an efficient reconfiguration during run time is enabled.

8. SUMMARY AND CONCLUSION

The concept of a generic protocol stack enables the vision of a multi-mode protocol and thus bridges the gap between wired and wireless network technologies. This concept is an application of the similarities of these networks from the perspective of protocol design. Its application results in an efficient as well as flexible approach to the design and implementation of communication protocols. The generic frame structure of a data link layer illustrates the advantages of generic protocol software. The multi-mode protocol stack is an encouraging approach of seminal protocol design under consideration of the above addressed research issues, which are of fundamental interest. Additionally, this promising concept will show its full potential in the context of software defined radio and reconfiguration of protocol stacks.

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