Wireless ATM LANs in Industrial Environments

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Abstract: *Industrial environments will represent a huge market for wireless LANs, especially for WLANs based on the ATM technology. However, several issues not found in other application areas have to be addressed. These concern the physical layer, the channel access scheme as well as service provisioning issues. This contribution presents and discusses our work which aims to adapt currently discussed WATM proposals to the requirements posed by industrial environments.*

Introduction:

In industrial environments such as production plants, chemistry facilities and automation systems we find a broad range of systems which have to communicate in a very flexible manner. An increasing number of mobile systems, like automated guided vehicles or intelligent transportation elements in commissioning and process automation systems will be controlled by computers installed on or inside these autonomous mobile units. Such vehicles have to communicate with control units for movement control, guidance and for application specific data exchange. Besides, non-real time data transfer, software and configuration data download as well as a mixture of multimedia services for surveillance and monitoring purposes take place [1].

As part of the project „ATMmobil“[1] we address the specific requirements of the described industrial application scenarios. These requirements demand research on all communication protocol layers.

At the anticipated high data rates, radio transmissions face hostile conditions in industrial environments. The negotiated quality of service may suffer severely from signal distortion due to multipath interference or from shadowing caused by obstructions in the signal path. This applies especially to time-critical applications like control of mobile units or production systems. Therefore efficient and robust transmission techniques in combination with adaptive error correction have to be provided. To avoid serious degradation of transmission quality and to provide quality of service guarantees, an efficient channel access protocol is necessary. The quality of service requirements range from short delays and high transmission reliability needed by a tremendous large number of connectionless operating low bitrate terminals, to high bitrates claimed by several users which for example are running video connections. This extremely broad range of different services is untypical to residential and office environments and therefore has not been investigated much in the past.

To provide full user and service mobility a Service Platform is demanded, which satisfies the requirements of users and multimedia applications in a mobile broadband environment.

This contribution describes the typical requirements which industrial environments pose on WATM systems and presents our work on the areas service platform, adaptive channel access schemes and transmission techniques. In the following we introduce a wireless scenario that includes typical present and future applications of industrial environments.

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[1] ATMmobil is funded by the German Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie.

Wireless Communications in Industrial Scenarios

Figure 1 describes an industrial scenario in which typical applications for wireless communications in a production plant are shown, including:

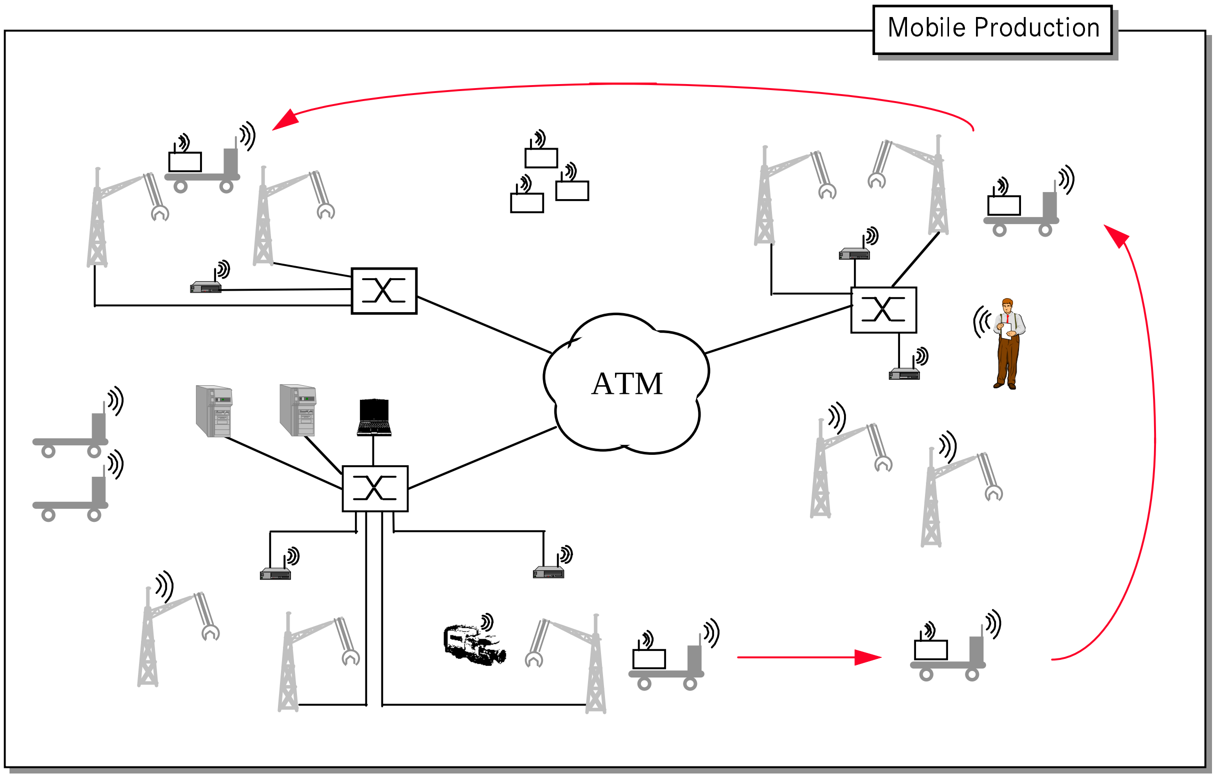

Figure 1. Industrial scenario including ATM and Wireless ATM systems.

- **Wireless access to systems that are reconfigured frequently.** In modern factories, machines are reconfigured frequently. The costs for re-cabling, installation of sensors and control units can be reduced by using wireless communication.
- **Flow of material, commissioning systems.** Autonomous transportation systems can help to optimize the flow of materials. Products, equipped with appropriate computing devices (e.g. Escort Memory Systems) can operate autonomously and thus trigger specific actions.
- **Mobile maintenance.** Service engineers and operation personnel using mobile computers and being able to walk around freely whilst querying data bases and even communicating for example with specialists.

These items are examples of typical applications in production facilities. They pose characteristic demands on different layers of the wireless communication systems. Their impacts on physical layer, medium access and service interface are discussed in the following sections.

Service Platform

To address the various requirements posed by the industrial scenarios and to support mobility in a generic way, a so called **Service Platform** [9] is developed. This platform specifies a general software-architecture to satisfy the needs of users and applications in a mobile broadband environment, especially being mobile and being able to use multimedia information. Generic security services for confidentiality and integrity are provided as well. The platform is realized as a set of services on top of the network layer and consists of several blocks to support signaling, session control and to manage the data stream (Figure 2).

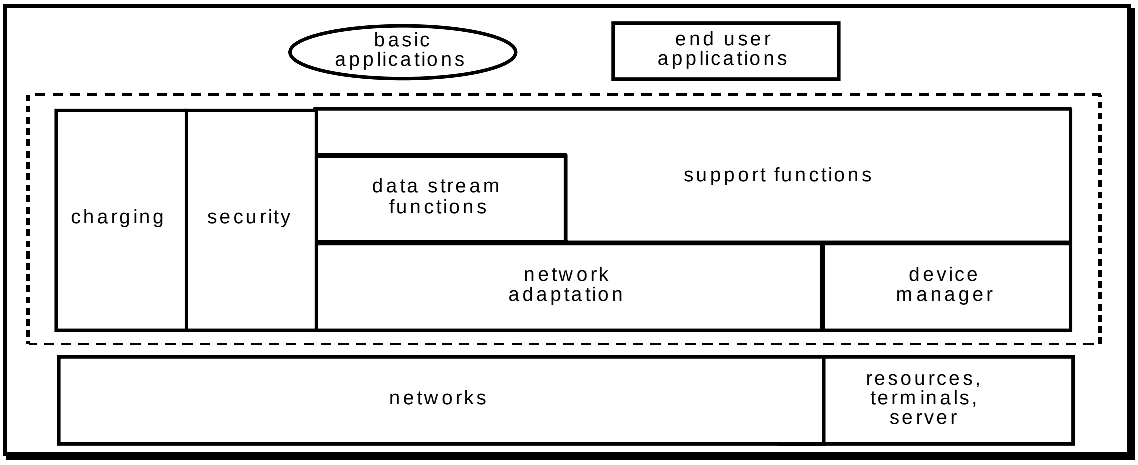

Figure 2. Service Platform

Roaming, user mobility management and interworking are provided by so called basic applications. The objective of the Service Platform is to hide the specific characteristics of the radio network to the application. It provides an unified service interface to the user or to the applications regardless where they are in the network and what kind of application is performed. In the following the typical functional blocks are briefly described:

- **Network Adaptation.** The Network Adaptation provides a generic interface for signaling and communication. It hides the specifics of the underlying protocol stacks (e.g. DECT, GSM, UMTS, wireless ATM) from the application.
- **Device Manager.** The Device Manager performs low-level hardware configuration control functions on the communication terminal and detects if the mobile station is inserted into docking station, the PCMCIA network adapter is replaced, and so on.
- **Data Stream Functions.** Data Stream Functions comprise the actual data. They include multimedia conversion, compression, en-/decryption, disconnection management.
- **Support Functions.** Signaling and control is provided by Support functions. These include Session Management, Location Management, Quality-of-Service Management, a Resource-and-Service Broker and a Management Information Base (MIB).
- **Security.** The Security functional block comprises functions for authentication, confidentiality, integrity as well as key-management.
- **Mobility Support.** This covers user-, terminal- and service-mobility. Portable devices, using wireless communication, can be attached to the network at arbitrary locations. Services are moved along with the portables. New concepts to select and locate the appropriate service (Service Trading, Resource Location) are introduced.

Implications on the Medium Access Control

Regarding the fact that future wireless industrial networks will support all services needed in the office application field as well as industrial control applications, we have to consider the question if such control applications for example for movement control of mobile vehicles are supported by the WATM service classes. Therefore, typical characteristics and requirements of such control applications [1] like up to several hundred mobile terminals, very low cell loss rate, cyclic as well as spontaneous transmissions, hard limits on transmission delay, connectionless transmissions between mobile terminals and fixed ones and transmission of alarms have to be taken into account.

The ATM service classes do not fit well since those which do not support real-time transmissions (UBR, ABR, nrt-VBR) are not employable and the other ones (CBR and rt-VBR) are on the one hand not flexible enough to support fast changing bitrates as needed to transmit spontaneous transmissions and on the other hand do not guarantee the requested low cell error rates. Therefore to be able to support industrial control applications additional mechanisms are needed.

The channel access in wireless ATM systems as discussed today will be controlled centrally by so-called base stations [7]. The base station has the task of controlling channel access in a way that quality of service parameters in the wireless ATM network are guaranteed. For that task a scheduling mechanism on the base station computes the access conditions (especially access times) of the mobile stations by taking into account the quality of service requirements of the virtual connections. The communication is organized in so-called frames. Figure 3 shows a possible TDMA/TDD frame structure. The frame is periodically initiated by the base station by sending a Frame Control Packet (FCP) containing information about the slot assignment and acknowledgements for previous transmissions.

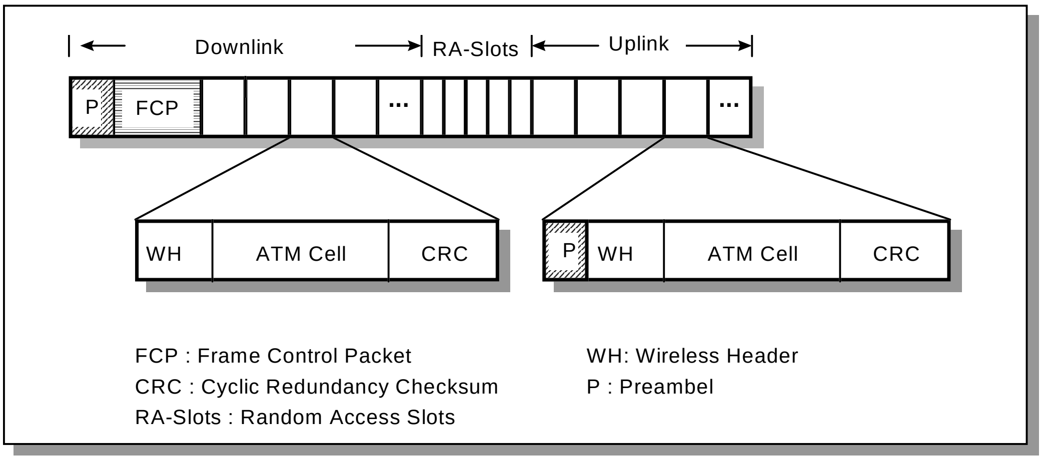

Figure 3.TDMA/TDD structure

The problem that arises now is how to signal bandwidth requests to the access point. Two mechanisms are proposed. First option is to signal via piggybacked dynamic parameters in every uplink cell. Those dynamic parameters could be the number of ATM cells waiting for transmission at the mobile station and the according cell deadlines, or an indicator for increasing or decreasing allocated bandwidth [6]. Second, uplink slots that are not dedicated to one mobile terminal can be accessed in a modified Slotted Aloha scheme.

We found by running simulations that access schemes based on the characteristics stated below will fulfill the requirements of industrial control applications. Therefore, we propose that a channel access scheme for industrial control scenarios should include the following elements ([8]):

- Frame based up- and downlink channels that are controlled centrally by a base station.
- Cyclic transmission scheduled by base station.
- Support of spontaneous transmissions by signaling bandwidth requests piggybacked with every uplink packet and by accessing random access slots.
- Prioritized access to random access slots and efficient (prioritized) collision resolution schemes.
- Detection, if a transmission slot is idle, or if a correct or distorted (collided) transmission took place by the base station and feedback of this information to the mobile stations.
- Information of the mobile stations about the next cyclic slot, which will be dedicated to them.

Transmission Techniques for Industrial Environments

Compared to residential or office environments, radio transmission in factory channels experiences significantly more distortion. RMS delay spreads up to 200ns are expected, resulting in a maximum excess delay of about 500ns [2]. The coherence bandwidth ranges between 1 MHz and 5 MHz and a maximum Doppler spread of 170 Hz is given at a carrier frequency of 5 GHz with a maximum mobility of 10 m/s. For the high data rates (>20 Mbit/s net user bandwidth, combined up- and downlink) anticipated in WATM networks, we therefore deal with a frequency selective, slowly time varying channel multicarrier code division multiplexing (MC-CDM) scheme.

In order to combat the deleterious fading effects present in frequency selective channels we employ MC-CDM as modulation technique based on orthogonal frequency division multiplexing (OFDM). The main advantage of OFDM results from the transformation of a frequency selective broadband channel into a sum of narrowband fading channels. Provided that a guard interval (circular prefix) of appropriate length is inserted between successive data blocks, the channel frequency selectivity is no longer generating intersymbol (-block) interference. Instead of performing a costly equalization by using an adaptive filter or Viterbi equalizer, the correction of the introduced multipath distortion affords only one single complex-valued multiplication per subchannel [3]. The set of correction factors can be easily computed after having estimated the channel transfer function. Even this channel estimation procedure is more efficient in terms of complexity and additional redundancy, compared to an equivalent single carrier scheme [4].

Although OFDM alleviates the problem of intersymbol interference, it does not suppress fading. In general the amplitudes of the discrete channel are Rayleigh distributed, leading therefore to a discrete Rayleigh fading channel substitute for the OFDM system. It is shown in [5] that when applying sufficiently long symbol spreading (in frequency direction) at the transmitter, together with iterative block decision feedback equalization (BDFE) at the receiver, the Rayleigh fading channel is approximately transformed into a set of parallel AWGN channels. Since the spreading can be carried out with a fast orthogonal transform, the additional complexity is moderate (equal to that of the FFT). Because the symbols are spread only over one block (every subchannel contains a portion of each input symbol), no bandwidth extension is necessary.

However, because of the nonlinear distortion introduced by the Rayleigh fading amplitudes, orthogonality of the spreading sequences is destroyed and has to be recovered by the BDFE. The symbol spreading and de-spreading extends the OFDM system to a multicarrier code division multiplexing (MC-CDM) system. The improvement of the channels' behavior is achieved through frequency diversity, established by equal spreading of the symbols over all subcarriers of the OFDM subsystem. Since the amplitudes of adjacent subchannels are correlated, it suffices to spread the symbols only over a fraction of the whole blocklength, together with interleaving them across the frequency domain. Thus the achievable diversity is reached with reduced complexity. Another advantage of exploiting frequency diversity by symbol spreading lies in the possible implementation of trellis coded modulation (TCM) with codes designed for AWGN channels. These codes perform considerably better than those developed for Rayleigh fading channels [5] and seem applicable if the transformed channel is close to a Gaussian one.

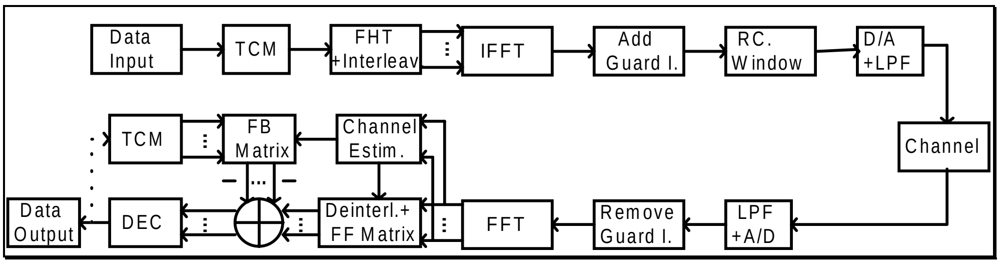

Figure 4: Block diagram of MC-CDM

Figure 4 shows the structure of a synchronous MC-CDM transmission system in baseband. At the transmitter a sequence of input data is coded and mapped to a modulation alphabet (8QAM or 16QAM) using trellis coded modulation. This sequence is divided into several blocks and each of them is spread by the fast Hadamard transform (FHT) and interleaved in frequency direction. For channel estimation redundancy is added to the symbol blocks. Each block of symbols is transformed by the inverse fast Fourier transform (IFFT) and the guard interval is added. In order to decrease the spectral sidelobes due to the sharp transitions at the block edges, the signal is further extended cyclically by a small amount in both directions and windowed by a raised cosine (RC) function. At the receiver, after conversion to digital, the extended guard interval is removed and the signal is transformed back by the fast Fourier transform (FFT). The transformed signal blocks are used to estimate the discrete channel transfer function, employing the method of pilot channels [4]. Furthermore each received block is deinterleaved and multiplied with the feedforward (FF) matrix of the BDFE. The goal of this transforms is to recover orthogonality and to perform the inverse FHT. The output is then decoded and a few iterations including TCM of the detected data and multiplication with the feedback matrix is carried out to improve detection performance. Simulations showed that two or three iterations suffice to reach near maximum performance [5]. Since even the calculations of the feedforward and feedback matrix are simple matrix multiplications with reduced order, it can be stated that the MC-CDM system together with the BDFE is a low complexity and flexible transmission system for frequency selective, slow time variant channels, experienced in industrial WATM-LAN environments.

Conclusion

The employment of wireless ATM systems in industrial environments pose several implications on system design that are not found in other application areas as office or consumer environments. The implications concern the radio transmission techniques as well as the medium access scheme and the provision of communication services. These implications are caused by aggravating radio channels and by applications that are not common to office scenarios and which demand hard quality of service guarantees. However, possible solutions to these implications fit well to the wireless ATM proposals currently discussed in ACTs projects like WAND, in the German ATMmobil project and last, but not least, presented at the ETSI standardization. Our objective is to influence the standardization in a way that future WATM radio networks will cover the necessary functionality for a successful employment in production and other industrial environments.

References

[1] High Performance Radio Local Area Networks (HIPERLANs). Requirements and Architectures for Wireless ATM Access and Interconnection". ETSI TR 101 031.

[2] Krizman D.M., Rappaport T.S., Ellison B.J., Seidel S.Y.: SIRCIM Plus: Simulation of Indoor Radio Channel Impulse response models with Impulse Noise. Version 2.0. 1997. *MPRG/Virginia Tech Intellectual Properties. Inc*.

[3] Lindner, J.: Channel Coding and Modulation for Transmission over Multipath Channels, *AEÜ*, No. 3, May 1995.

[4] Bossert M., Donder A., Trushkin A.: Channel Estimation and Equalisation in Orthogonal Frequency Division Multiplexing Systems. *ITG Tagung Mobilkommunikation*. Neu Ulm. 1995.

[5] Reinhardt M., Lindner J.: Transformation of a Rayleigh fading channel into a set of parallel AWGN channels and its advantage for coded transmission. *Electronics Letters*. Vol. 31. No. 25. December 1995.

[6] C. Sinner, M. Wolf: Adaptives Scheduling in zentral verwalteten ATM Netzen (in German). to appear. MMB'97. Freiberg. September 1997.

[7] Magic WAND, Wireless ATM MAC Overall Description. The Magic WAND Deliverable 3D1 http:\www.tik.ee.ethz.ch/~WAND

[8] M. Wolf, W. Franz, C. Sinner, R. Sigle: Industrial Environment: Implications for the MAC Protocol. ETSI BRAN TD 16. July 1.-4. Tampere 1997.

[9] N. Diehl, D. Grill, A. Held, R. Kroh, T. Reigber, Th.Ziegert: System Integration for Mobile Computing. Distributed Platforms. ICDP `96. Chapman & Hall. 1996.