THE CELLULAR TEXT TELEPHONE MODEM – THE SOLUTION FOR SUPPORTING TEXT TELEPHONE FUNCTIONALITY IN GSM NETWORKS

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ABSTRACT

Text telephone devices are text-based terminals that allow the users to communicate by text via fixed-line telephone networks. Since cellular phone systems are sometime subject to severe radio channel impairments and the modem signals of these text telephones are therefore not always transmitted reliably, the Federal Communications Commission (FCC) has required a solution to guarantee a reliable transmission of text telephone data for emergency calls via cellular phone systems. For the North American PCS-1900 cellular phone systems recently the Standards Committee T1 has standardized a solution for this requirement, which is based on a new modem protocol, the Cellular Text Telephone Modem (CTM), whose signals can be reliably transmitted via the speech channel of cellular phone systems. After a short introduction into text telephony, this contribution provides a description of this solution for PCS-1900 systems using CTM signals. The solution is indeed independent of the cellular system and works on de-facto all speech channels.

1. INTRODUCTION TO TEXT TELEPHONY

In the United States, text telephone devices (TTY terminals) have achieved high importance for the conversation of hearing impaired persons via telephone lines. In contrast to other text-based communication services, like e.g. e-mail, text telephones are used for the interactive conversation between the subscribers. Furthermore, text telephones allow the alternating use of text and speech transmission, because all data is transmitted via a regular speech channel.

A TTY terminal consists of a keyboard, a text-oriented display, and a modem, which transforms the text telephone characters into audio signals that can be transmitted via the speech path of the telephone network. The protocols used by text telephone devices vary regionally. A description of the most important text telephone modem protocols is provided in [1]. In North America, beside some proprietary transmission protocols, the most important standardized modem protocol is the *Baudot Code*. This modem protocol provides half-duplex transmission of text characters encoded with 5 bits per character at a transmission rate of 45.45 bit/s. Baudot Code is based on a frequency shift keying (FSK) modulation scheme using the frequencies 1400 Hz and 1800 Hz.

2. TEXT TELEPHONY IN CELLULAR PHONE SYSTEMS

In spite of its low transmission rate and its restricted character set, in North America TTY terminals are commonly used by hearing impaired persons for communicating via fixed telephone networks. However, connecting a TTY terminal to a digital cellular phone results in unsatisfactory character error rates. This loss of performance is caused by the fact that digital cellular phone systems are optimized for speech signals. Apart from the distortions of the speech codec, the impairments that result from a potentially weak radio channel and from the error concealment that has been designed for speech signals may cause high distortions of the transmitted Baudot Code signal. A further problem might be the discontinuous transmission (DTX) of some cellular phone systems, if the voice activity detection (VAD) classifies the Baudot Code signal as non-speech.

In the US the Federal Communications Commission (FCC) has required a solution to guarantee a reliable transmission for all TTY emergency calls via cellular phone systems to public safety answering points [2]. Solutions that have to be developed by cellular telecommunications industry shall guarantee the interoperability with existing TTY terminals. Text telephones connected to cellular phones shall offer the same functionality as in case of a PSTN connection, which includes the alternating use of text and speech transmission. Therefore, an appropriate solution can not be based on data services. Also the requirement of emergency calls without having a subscriber identification module (SIM) implies that any solu-

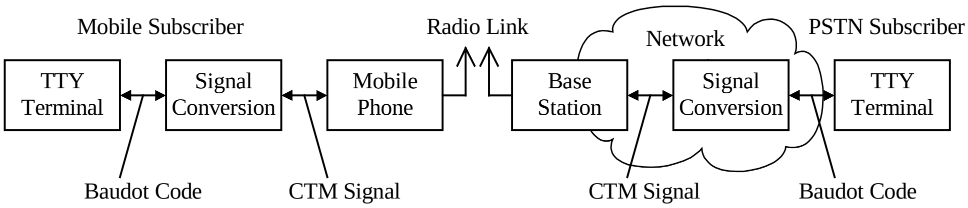

Fig. 1. Text telephone call from a cellular phone to a PSTN subscriber with signal conversion from Baudot Code to CTM signals and vice versa at both sides of the radio link.

tion for fulfilling the FCC requirement must be based on speech calls.

In order to fulfil the FCC requirement, for the North American cellular phone standards CDMA, TDMA, and GSM (PCS-1900) recently two different solutions have been standardized.

3. SOLUTION FOR CDMA AND TDMA SYSTEMS: MODIFICATION OF THE SPEECH CODEC

For the cellular phone networks based on CDMA and TDMA technology, a solution has been chosen that requires a modification of the speech codec [3]. The speech encoder is extended by a decoder for Baudot Code signals. As soon as a Baudot Code signal is detected, the speech encoder is set into a special TTY mode and some of the speech parameters, like the LTP lag information, are used for transmitting the TTY information bits. This encoding of the TTY information bits is designed such that an unmodified speech decoder, which is not able to decode the TTY bits, will regenerate the original audio signal with minor additional distortions.

However, in order to benefit from the digitally transmitted TTY information, also the speech decoder has to be modified. Generally spoken, the speech decoder is extended by a Baudot Code modulator, so that the original Baudot Code signal can be regenerated as soon as the speech decoder receives speech frames that contain encoded TTY information.

Since this solution is integrated into the speech codec, it has to be adapted individually for each speech coding standard that is used in these systems. In order to guarantee TTY functionality, a modification of all speech codecs (transcoders) within the network is required. Furthermore, also the user has to purchase a new mobile phone with the modified speech codec, if he wants to take advantage of the improved TTY transmission capabilities.

4. SOLUTION FOR GSM SYSTEMS: USE OF AN ENHANCED MODEM SIGNAL

The PCS-1900 system is based on the global GSM standard and therefore a global solution for text telephony had to be found. Since text telephony outside the US is not only based on Baudot Code, but on a handful of other methods, which are specified [1], a modification of the existing and future GSM speech codec standards would have been an inappropriate solution. Furthermore, the implementation of specific TTY detectors and regenerators into all speech codecs within the mobile communication network would have prohibited any future evolution of text telephony.

Therefore, Working Group T1P1.3 of the *Standards Committee T1 Communications*, which is responsible for GSM and UMTS systems in the US, has decided that the support of text telephony in PCS-1900 systems shall be achieved by the use of an enhanced modem protocol that includes sufficient robustness for reliable transmission via any kind of speech channel. Using such a sophisticated modem, the network infrastructure and especially the speech codecs can be maintained, provided that a signal conversion from the old Baudot Code into the new modem signal is applied before the transmission via the radio link. After the transmission via the radio link, the original Baudot Code has to be regenerated, as it is indicated in Fig. 1. In contrast to the solutions for the CDMA and TDMA networks, this approach offers a much higher flexibility, because the signal conversion does not have to be integrated into the speech codec.

The authors of this paper have been substantially involved in the design and the standardization of a sophisticated modem protocol for the transmission of text data via cellular phone systems. This modem, which has been standardized by T1P1.3 under the name *Cellular Text Telephone Modem* (CTM) [4], will be described in the following.

5. OVERVIEW OF THE FUNCTIONAL COMPONENTS OF CTM

Figure 2 depicts an overview of the functional components that are required for the signal conversion between Baudot Code and CTM signals. In addition to the CTM modem, which has been standardized in [4], also a Baudot Code modem, as it is specified in [1], as well as a bypassing mechanism for non-data signals is required.

The Baudot Code Decoder is responsible for the detection and the decoding of any Baudot Code signal that is present at the input of the signal conversion module. The decoded text characters, which are available at the output

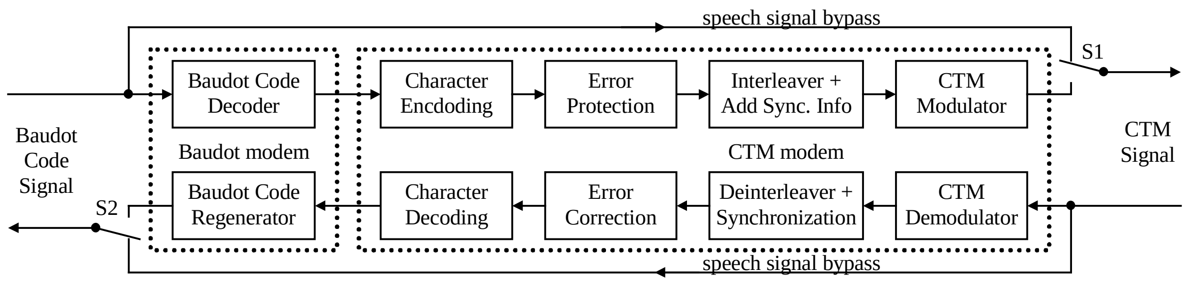

Fig. 2. Overview of the functional components for the signal conversion between Baudot Code and CTM signals.

of the Baudot Code decoder, are modulated into a CTM signal by the transmitting parts of the CTM modem. For the backward link, the corresponding functions apply, i.e. the CTM signal is decoded by the receiving components of the CTM modem and the decoded text characters are modulated by the Baudot Code regenerator.

For normal speech calls, which do not contain TTY data, the signal conversion module must allow the transparent bypass of speech signals in both directions. Therefore, the structure in Fig. 2 includes transparent bypassing paths for both directions. The switches S1 and S2 remain in bypass position as long as the corresponding decoders have not detected a Baudot Code signal or a CTM signal, respectively.

5.1. Character Encoding

In contrast to Baudot Code, which is restricted to a character set of less than 60 different characters, the character encoding of CTM is based on ISO/IEC 10646-1, which supports uppercase and lowercase characters as well as international character sets.

5.2. Error Protection

In order to guarantee a reliable transmission of text messages in case of weak radio channels, the net bit stream is protected against transmission errors by means of a r=1/4 convolutional encoder with a constraint length of K=5. The corresponding decoder can be based on the Viterbi algorithm.

5.3. Interleaving and CTM Burst Structure

In order to cope with the time-varying characteristics of a radio channel that is subject to fading, the gross bits are interleaved by a convolutional interleaver.

The Cellular Text Telephone Modem is based on a synchronous transmission using an adaptive burst length. Each burst is preceded by a preamble that is used for the initial synchronization of the receiver. An active CTM burst is continued as long as there are characters available for the transmission. As soon as Baudot Code decoder is no longer able to provide text characters, the CTM burst is terminated. In order to allow the receiver to keep the synchronism even after a cell hand over, a resynchronization sequence is inserted periodically into the bit stream as long as the burst is active.

5.4. Modulation Scheme

Since modern speech coding algorithms aim at the reduction of speech signal components that are irrelevant for the human ear, a modem for data transmission via speech codecs should not be based on any kind of phase shift keying (PSK) modulation. Therefore, the Cellular Text Telephone Modem uses a Frequency Shift Keying (FSK) modulation scheme. In order to achieve compliance with the GSM Full Rate speech codec, which applies a low-pass filter with a cut-off frequency of 1.3 kHz to the residual signal after the long-term prediction, the highest frequency used for CTM is 1000 Hz. A further restriction is that speech coding strategies assume that the speech signal parameters change at a slow rate. Therefore, for the Cellular Text Telephone Modem a low symbol rate has been chosen with a symbol length of 5 ms. Each symbol consists of a sine waveform of one of the four frequencies 400 Hz, 600 Hz, 800 Hz, and 1000 Hz. This design allows to encode two bits in parallel within each 5 ms interval. Therefore, the gross bit rate of the modem is 400 bit/s.

6. PERFORMANCE EVALUATIONS

The Cellular Text Telephone Modem has been designed to guarantee a robust transmission of text telephone data via the speech channel of cellular phone systems. In the following, we will characterize the performance of CTM for a transmission of a text message of 4276 characters via a simulation of the PCS-1900 GSM AMR speech channel with a speed of 3.0 km/h of the mobile station.

For a radio channel without frequency hopping, a text data transmission using the original Baudot Code results in unacceptable character error rates of more than 5 % for all modes of the AMR speech codec, if the carrier-to-interference ratio C/I of the radio channel is 12 dB or worse. Table 1 shows that in contrast to Baudot Code, CTM guarantees an acceptable character error rate of less than about 1 % for most of the modes of the AMR codec, if a full-rate channel with an C/I of 6 dB or better is considered. For the half-rate channel, the C/I must be better than

Channel C/I	4.75 kbit/s		5.15 kbit/s		5.9 kbit/s		6.7 kbit/s		7.4 kbit/s		7.95 kbit/s		10.2 kbit/s		12.2 kbit/s	
	FR	HR	FR	HR	FR	HR	FR	HR	FR	HR	FR	HR	FR	HR	FR	HR
14 dB	0.02	0.14	0.00	0.07	0.02	0.00	0.02	0.05	0.00	0.05	0.00	0.14	0.00	—	0.02	—
12 dB	0.00	0.12	0.02	0.07	0.02	0.02	0.00	0.07	0.00	0.02	0.02	0.17	0.02	—	0.05	—
10 dB	0.07	0.52	0.02	0.76	0.02	1.04	0.05	0.83	0.02	0.74	0.00	0.88	0.07	—	0.28	—
8 dB	0.17	2.59	0.33	2.82	0.05	2.49	0.09	2.82	0.17	2.49	0.12	3.23	0.40	—	0.71	—
6 dB	0.88	6.97	1.54	9.27	1.14	9.94	1.35	10.56	1.33	10.70	0.81	11.88	3.13	—	5.05	—

Table 1. CTM Character Error Rates in % for a transmission via the PCS-1900 GSM AMR speech channel without frequency hopping, speed of the mobile station 3.0 km/h.

about 10 dB to obtain a character error rate that is better than 1%.

The character error rates are reduced significantly, if an AMR channel with frequency hopping is considered. With the exception of 12.2 kbit/s mode, CTM achieves character error rates lower than 0.1 % for all modes of the AMR codec, if a full-rate channel with a C/I of 4 dB or better is considered.

7. IMPLEMENTATION OPTIONS FOR CTM

In order to provide the advantages of the Cellular Text Telephone Modem for existing text telephones, a signal conversion between the old Baudot Code signals and the new CTM signals has to be provided at both sides of the radio link, as it is indicated in Fig. 1. At the mobile subscriber’s side the signal conversion might be integrated into the mobile phone or could be provided by a special accessory, which can be attached to the mobile phone. The signal adaptation becomes redundant as soon as new TTY terminals will be able to run the CTM protocol.

For the network side, also a signal conversion has to be provided for the interoperability with TTY terminals connected to PSTN lines. One solution is to attach this signal conversion to the speech codec, which results in a “co-located” solution that is similar to the structure of the solution for CDMA and TDMA networks. However, attaching this functionality to all speech codecs within the core network requires a high effort.

Due to the fact that only a small amount of all calls require the TTY functionality, a more reasonable solution is the insertion of a centralized service node into the core network. With this solution, only those calls that require TTY functionality have to be routed via this service node, while all other calls can be routed as before. In practice, depending on the extensions of a given network, one would insert more than only one service node, also for reliability reasons, but still a limited number.

Apart from the advantage of a lower impact to the core network, this solution also guarantees that the quality of non-TTY calls is not degraded. Since every Baudot Code detector implies the risk of false detections, only a solution, where Baudot Code signal detector and regenerator are not present in normal voice calls, can guarantee that these calls are never disturbed by generating Baudot Code signals.

Furthermore, only a centralized solution like a service node allows to consider future improvements of text telephony, whereas an integration of the Baudot Code modem into every speech codec within the core network would prohibit any evolution of text telephone modem standards in the future.

8. CONCLUSIONS

The Cellular Text Telephone Modem is a solution for providing text telephone support in PCS-1900 cellular phone systems. The ability of low bit rate data transmission within the speech channel is achieved by the introduction of a new modem protocol. Due to its high robustness against degradations caused by the speech codec or a possibly weak radio channel, the new modem guarantees low character error rates even in case of poor radio channel conditions. This selected solution for PCS-1900 can be implemented with minimum impacts to the cellular and core network. In addition, the implementation on a centralized service node implies a lower maintenance effort so that future improvements of text telephony can be supported more easily. The CTM solution is not directly coupled to the characteristics of the PCS-1900 cellular system, but can be applied on de-facto every speech channel. Since the service node is located somewhere in the core network, the TTY support can also be provided when the user is roaming to other networks.

9. REFERENCES

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[4] T1P1 document No. 2000/182R1, “Draft proposed American National Standard for Telecommunication; PCS 1900 – Cellular Text Telephone Modem (CTM) General Description”