SPECTRUM EFFICIENCY OF RADIO DATA SYSTEM (RDS)

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Abstract - **This paper addresses the use of the Radio Data System (RDS) for datacasting road traffic information. We conclude that, although RDS may be is essential to the early phases of introduction of novel Advanced Traffic Information Systems (ATIS), FM subcarrier transmission does not offer a spectrum efficient solution for large-scale ATIS datacasting. The conclusions are believed relevant to the spectrum-efficient design of the future datacasting networks.**

Introduction

For a long time, radio and television have been the only means for electronically disseminating information to large groups of people. However, new techniques such as datacasting are being developed and introduced rapidly. Traffic and transportation appears to be an area where many such innovations are taking place. The growth of the road traffic, and the increasing inconvenience and environmental damage caused by congestion require better use of the infrastructure for physical transport. Advanced Traffic and Transportation Management and Information Systems (ATM/IS) appear promising to relieve the current congestion problem. Over the last years it has become clear that ATMS and ATIS will require a substantial wireless communications infrastructure. Yet, it is unclear whether the communication services are best provided by a single uniform radio access technique, suitable for any propagation environment and for any set of services, or, alternatively through specialized radio networks, each developed to offer only a selected set of data transport services. This situation is similar to the discussions and standardization processes in other 'hot' areas of new developments in wireless communications, such a personal communications systems and wireless office systems. For reasons of terminal power consumption, the European standard for cordless telephony (DECT) essentially differs from (and is non-compatible with) the GSM standards for vehicle-mounted terminals. Moreover, for reasons of spectrum efficiency and user capacity, the design of packet-switched radio data networks, such as Mobitex, essentially differs from circuit-switched cellular networks. Theoretical results on the spectrum efficiency of radio networks, e.g. in [1] and [2], appear to confirm that a "universal", i.e., integrated approach appears less desirable in wireless subscriber access links than in cable or fiber-optic backbone (ISDN) links. Nonetheless, there is clear need for systems that can offer universal *services*, even though hybrid, non-uniform radio access techniques might be used. For Intelligent Vehicle Highways Systems (IVHS) services, a school of researchers and decision makers have adopted the position that IVHS is to be supported through an architecture of hybrid physical-layer technologies [3], including for instance RDS subcarrier transmission [4].

Success factors of telematic innovations

A study [5] into the success factors of new information systems concluded that the chances of a successful market introduction of a new service and a new technology at the same time are small. More likely is a two-step introduction of a new service (possibly initially supported by inadequate technology) followed by improvements in technology to upgrade the service. This two-step introduction appeared a direct consequence of the classical telecommunications dilemma of the simultaneous need for a (standardized) infrastructure, a sufficiently large group of subscribers and a sufficiently valuable service for an innovation to become successful. Examples of recent successful market introductions are the datacasting services, such as teletext, using subcarrier modulation of television broadcast signals: new service using existing technology, or more importantly an existing infrastructure. On the other hand, the Compact Disk (CD) replaced the ancient technology of long-play disks, but provided the same service at a much improved quality. The more recent introduction of the CD-ROM could presumably only be successful after large-scale acceptance of the CD technology for music reproduction.

From these observations, it appears crucial that early experimental services for IVHS can be provided through inexpensive communication means, thus based on an existing infrastructure. For this very reason, radio and television broadcast facilities appear suitable for experiments with ATM/IS applications and traveller-oriented services. Examples are the U.S. Transport Advisory Radio (HAR and AHAR) and subcarrier voice or data messages on FM and TV transmitters [6]. The European Radio Data System (RDS) system, the German Autofahrer Rundfunk Information (ARI) and the British CARFAX all use such subcarrier transmission.

RDS System model

In the RDS system [4, 6], an antipodal data signal is modulated on a 57 kHz subcarrier and added to the FM multiplex stereo signal. The subcarrier frequency of f_{RDS} = 57 kHz is chosen because it is an harmonic of the 19 kHz pilot tone, which facilitates synchronization. The subcarrier itself is suppressed to make the system compatible with German Autofahrer Rundfunk Information (ARI) system which uses a 57 kHz subcarrier to identify radio stations offering traffic information. The modulation scheme of RDS involves differential coding on biphase and bandlimited waveforms. The bit rate r_b is 1187.5 bit/s, so the bit time T_b is 0.84 msec. The frequency deviation of the RDS subcarrier is denoted as $f_{\Delta,RDS}$. The deviation standardized by the EBU ranges from $f_{\Delta,RDS}$ = 1 kHz to 7.5 kHz, but we assume that the broadcaster is free to optimize $f_{\Delta,RDS}$ according to his particular audio and data coverage needs, with $0 \le f_{\Delta,\mathrm{RDS}} \le f_{\Delta,}$ where f_Δ maximum (peak) deviation frequency of the FM transmitter (f_Δ = 75 kHz). Addition of the RDS subcarrier signal requires reduction of the peak audio deviation $f_{\Delta,\mathrm{AUD}}$, according to the zero-sum game

$$f_{\Delta,\mathrm{AUD}} + f_{\Delta,\mathrm{RDS}} \le f_\Delta = 75 \text{ kHz}$$

Neglecting Doppler spreads and random FM modulation caused by multipath fading, the BER of the RDS signal is mainly determined by the signal-to-noise ratio at the FM discriminator output. It is well known that this noise has the quadratic power spectrum [7]

$$G_n(f) = \frac{N_0 f^2}{2S_R}$$

where N_0 is the noise power density (in watt per Hz) at the receiver front end. The received (local-mean) signal power S_R can be obtained from CCIR field strength curves, using the expression $S_R = E^2/(120\pi)$ with E the local electric field strength. Lacking mathematical expressions or approximations of these curves, we assume UHF groundwave propagation. Egli [8] suggested the semi-empirical propagation model

$$S_R = \frac{h_T h_R}{d^4}\left(\frac{f_c}{40 \text{ MHz}}\right)^2 G_R G_T S_T$$

where f_c is the carrier frequency (88.5 MHz < f_c < 108 MHz), h_T and h_R are the transmit and receive antenna heights, G_R is the receive antenna gain, and $G_T S_T$ is effectively radiated power (ERP). For the following analyses, the most important observation from the above expression is that the received signal power vanishes with distance d to the power −4, which is substantially faster than in free space propagation.

SNR for audio broadcast signal

For the reception of the main broadcast program in the range of audio signal-to-noise ratios addressed by the CCIR recommendations, i.e., for RF C/N ratio largely above the FM detection threshold, the (mono-phonic) audio SNR becomes a linear function of the RF C/N ratio, with [7]

$$\mathrm{SNR} = \left(\frac{f_{\Delta,\mathrm{AUD}}}{B_{de}}\right)^2 \frac{S_X S_R}{N_0 W}$$

where W is the audio bandwidth (W = 15 kHz), B_{de} is the pre-emphasis turnover frequency, S_X is the average power in the audio program normalised to a unity peak level ($0 \le S_X \le 1$), determined by the degree of audio processing. The peak frequency deviation of the audio signal is denoted as $f_{\Delta,\mathrm{AUD}}$. Reducing the peak audio deviation by a factor $f_{\Delta,\mathrm{AUD}}/f_\Delta$ relative to the maximum frequency deviation of 75 kHz reduces the coverage area πd_{AUD}^2 of the main audio program by a factor of $f_{\Delta,\mathrm{AUD}}/f_\Delta$. This can be seen from

$$\mathrm{SNR} = S_X \frac{G_R G_T S_T}{N_0 W B_{de}^2} \frac{f_{\Delta,\mathrm{AUD}}^2}{d_{\mathrm{AUD}}^4}$$

where SNR, S_X, G_R, G_T, S_T, N_0, B_{de} and W are taken constant. The observation that the service area reduces proportional to $f_{\Delta,\mathrm{AUD}}$ is not to restricted to monophonic transmission, as assumed in the above expression, but also holds for stereophonic broadcasts.

BER of the RDS Signal

Despite its quadratic shape, we approximate the post-discriminator spectrum to be flat over the narrow bandwidth (54.6 - 59.4 kHz) of the RDS signal. The noise spectral density at f_{sc} is $N_{rds} = N_0 f_{sc}^2/2S_R$. For the antipodal RDS signal, the BER is

$$\mathrm{P}[e] = \frac{1}{2}\mathrm{erfc}\sqrt{\frac{E_b}{N_0}} = \frac{1}{2}\mathrm{erfc}\sqrt{\frac{f_{\Delta,RDS}^2 T_b}{f_{sc}^2}\frac{S_R}{N_0}}$$

since the energy per bit is $E_b = f_{\Delta,\mathrm{RDS}}^2 T_b/2$ with T_b the bit duration. However, in mobile (IVHS) reception without a direct line-of-sight from the broadcast transmitter, Rayleigh multipath fading is likely to be encountered. We address 'frequency non-selective' (flat) fading, i.e., the rms multipath delay spread T_{rms} is assumed to be much less than $(2\pi B_{\mathrm{FM}})^{-1}$ with B_{FM} the FM transmission bandwidth ($B_{\mathrm{FM}} \approx$ 300 kHz, thus $T_{rms} \ll 0.5$ sec), and 'slow' fading, i.e., the antenna is assumed to move less than $\lambda/6$ during one bit time, so the vehicle speed is assumed to be much less than $\lambda/(6T_b) \approx 200$ m/s. Under these reasonable assumptions, the received instantaneous power is exponentially distributed with (local-) mean power S_R, where S_R can be found from Egli's path loss law. This gives a local-mean BER of [1, 9]

$$\mathrm{P}[e] = \frac{1}{2} - \frac{1}{2}\sqrt{\frac{f_{\Delta,RDS}^2 T_b S_R}{f_{\Delta,RDS}^2 T_b S_R + N_0 f_{sc}^2}}$$

Spectrum efficiency of RDS datacasting

The most efficient method known for planning of M parallel FM broadcast networks (program channels) each with contiguous (national) coverage requires $B_{M\,\mathrm{NETS}}$ = 0.7 + M 2.1 MHz [10]. This number is not met in historically developed national frequency plans, which typically require more spectrum resources for contiguous coverage. This result takes into account not only the bandwidth per FM transmission B_{FM} (≈ 300 kHz) but also the size of the CCIR coverage area relative to the protection area where the same frequency cannot be reused without causing unacceptable interference. Here we will use the result to argue, that the spectrum cost $B_{\mathrm{FM\,NET}}$ (expressed in exclusive, non-reusable MHz·m²) of a particular FM radio broadcast station is (at least) 2.1 MHz times the size of its CCIR coverage area. This happens to correspond to approximately seven times the transmission bandwidth B_{FM}, which also occurs in cellular telephony networks.

Hence, the spectrum resources B_{RDS} associated to this loss of transmitter coverage is $1 - f_{\Delta,\mathrm{AUD}}/f_\Delta$ times $B_{\mathrm{FM\,NET}}$, or $B_{\mathrm{RDS}} = (f_{\Delta,\mathrm{RDS}}/f_\Delta)\, B_{\mathrm{FM\,NET}}$. Thus, for the recommended values of $f_{\Delta,\mathrm{RDS}}$, introduction of RDS on all radio stations removes 1.3 to 10% of the FM broadcast spectrum resources from audio programming. This corresponds to 28 kHz to 210 kHz for contiguous spatial coverage by a single RDS signal.

We will now proceed with a more detailed investigation of the spectrum required for RDS coverage, assuming that one can optimize $f_{\Delta,\mathrm{RDS}}$ to minimize the spectrum cost of RDS datacasting. We use A to denote the portion $A = (d_{\mathrm{RDS}}/d_\Delta)^2$ of the principal coverage area of the FM transmitter that is covered with RDS reception with a better local-mean BER than P_{RDS}, relative to the coverage area if the full deviation f_Δ was be used for the audio program. A can be obtained from

$$P_{RDS} = \frac{1}{2}\mathrm{erfc}\sqrt{\frac{f^2_{\Delta,\mathrm{RDS}}T_b}{f^2_{sc}}\frac{S_R}{N_0}\frac{d_{f_\Delta}^{\;4}}{d_{\mathrm{RDS}}^{\;4}}} = \frac{1}{2}\mathrm{erfc}\sqrt{\frac{f^2_{\Delta,\mathrm{RDS}}T_b}{f^2_{sc}}\frac{S_R}{N_0 A^2}}$$

for a non-fading (line-of-sight) propagation environment, and

$$P_{RDS} = \frac{1}{2} - \frac{1}{2}\sqrt{\frac{f^2_{\Delta,\mathrm{RDS}}T_b S_R}{f^2_{\Delta,\mathrm{RDS}}T_b S_R + N_0 f^2_{sc} A^2}}$$

for a flat, slowly Rayleigh-fading environment.

After some straightforward algebraic operations with the latter expression, the RDS-covered portion A of the transmitter's maximum coverage area is found as

$$A = \frac{f_{\Delta,\mathrm{RDS}}}{f_{sc}}\sqrt{1-(1-2P_{RDS})^2}\sqrt{\frac{T_b S_R}{N_0}} \approx 2\frac{f_{\Delta,\mathrm{RDS}}}{f_{sc}}\sqrt{P_{RDS}}\sqrt{\frac{T_b S_R}{N_0}}$$

for $P_{RDS} << 0.5$.

In contrast to the common practice for wide-area wireless data networks to express the spectrum efficiency in bit/sec/Hz/km^2, we express the spectrum efficiency of the RDS datacasting service in bit/sec/Hz. The reason for this is that in the case of datacasting, we address contiguous coverage by a single data signal, rather than sending messages to specific individual users with a certain spatial density. The spectrum efficiency of the RDS subcarrier $\mathrm{SE_{RDS}}$ is

$$\mathrm{SE_{RDS}} = \frac{A r_b}{B_{\mathrm{RDS}}} \approx \frac{2 r_b}{B_{\mathrm{FMNET}}}\frac{f_\Delta}{f_{sc}}\sqrt{\frac{P_{RDS}T_b S_R}{N_0}}$$

$$= \frac{2\sqrt{r_b}}{B_{\mathrm{FMNET}}}\frac{f_\Delta}{f_{sc}}\sqrt{P_{RDS}}\sqrt{\gamma_{\mathrm{CCIR}}B_{\mathrm{FM}}}$$

bits per sec per Hz. At the fringe of the CCIR coverage area, the CCIR recommends an RF C/I protection ratio γ_{CCIR} of at least (30.000 or) 45 dB for stereophonic broadcasting, which is achieved by the method [10] used here for reference. Inserting the appropriate values gives

$$\mathrm{SE_{RDS}} = 0.041\sqrt{P_{RDS}}$$

bit per sec per Hz.

Dedicated IVHS radio network

If, on the other hand, IVHS datacasting services are offered through a dedicated (cellular) data network using antipodal (BPSK-type) modulation, rather than the two-step subcarrier method adopted for RDS, the BER in a frequency non-selective slowly Rayleigh-fading channel is [1, 9]

$$\mathrm{P}[e] = \frac{1}{2} - \frac{1}{2}\sqrt{\frac{\gamma}{1+\gamma}} \approx \frac{1}{4\gamma}$$

where the signal-to-noise-plus-interference ratio γ at the cell boundary d_R is mainly determined by co-channel interference from six other cells. Given the reuse distance d_{ru} or the cell cluster size C (C = 1, 3, 4, 7, 9, ..), we obtain

$$\gamma = \frac{1}{6}\frac{d_{ru}^4}{d_R^4} = \frac{9C^2}{6}$$

since the relation between the normalised reuse distance d_{ru}/d_R and the number of different cell frequencies C is $d_{ru}/d_R = \sqrt{(3C)}$ for a hexagonal cell-layout [1]. So the required minimum cluster size to satisfy a maximum bit error rate P_{RDS} is $C = (6P_{\mathrm{RDS}})^{-1/2}$. The spectrum efficiency is

$$\mathrm{SE_{IVHS}} = \frac{r_b}{B_T\,C} \approx \frac{r_b}{B_T}\sqrt{6P_{RDS}}$$

where B_T is the bandwidth needed to accommodate a bit rate r_b. Typical modulation techniques offer r_b/B_T = 0.5 bit/s/Hz. We conclude that the spectrum efficiency $\mathrm{SE_{IVHS}}$ of a dedicated datacasting network is in the order of magnitude $1.22\sqrt{P_{\mathrm{RDS}}}$ bit/sec/Hz.

Conclusion

A number of technical reports and papers have described the RDS system as a method to add data signals to an FM radio broadcast service, with negligible degradation of the audio signal coverage. In this report, we formulated an analytical model to estimate the broadcast spectrum used per RDS bit and we have compared it to a generic cellular radio network dedicated for datacasting. In our analysis we used the audio SNR that occurs for a full frequency deviation (75 kHz) at the recommended CCIR RF protection margin as the benchmark for our comparisons. We conclude that addition of RDS subcarriers to existing FM radio stations appears not a spectrum-efficient method for datacasting to mobile recipients. A dedicated cellular data network can typically offer this service 30 times more efficiently.

Previous arguments that RDS has negligible effect on the FM audio coverage appear to be correct only if one relates the spectrum occupation (in Hz/sec/km^2) of RDS to the large bandwidth for the FM modulated audio signals, rather than - more appropriately - to the quite small data rate (1187.5 bit/s) offered by an RDS subcarrier.

Despite its inefficient nature, the use of existing FM broadcast facilities for disseminating data appears crucial for successful market introduction of novel datacasting services. Therefore RDS is likely to play an essential role in early implementations of such services. Moreover, the very combination of offering audio programs, containing for instance news and traveller information, and providing RDS traffic data can be a very useful one in some radio broadcast markets. From a spectrum efficiency point of view, it would however, not be a wise decision to rely on RDS type of subcarrier transmission for widespread operation of future IVHS services. A dedicated IVHS communication infrastructure could offer these services in a substantially more efficient way. This results is believed relevant to the long-term implementation of IVHS communication networks and the role radio broadcasters can play in offering traffic information via RDS of via cellular networks, particularly since some countries have introduced or consider introducing a spectrum fee to ensure economic forces to govern the use of resources [11].

As future IVHS services are likely to become more sophisticated and communication intense, with a mature market penetration of ATM/IS, a larger user capacity, higher reliability of the transmission and lower delays are needed than can be provided by the existing concepts. Moreover, cost-effective (high volume) manufacturing of ATM/IS devices for a mass market can not accept an excessively diverse set of radio specifications, with carrier frequencies ranging from AM-band radio (1MHz) to many

GHz, with receiver bandwidths ranging from a few kHz for voiceband up to multiple MHz for spread-spectrum signals with ISM-band interference scenarios. Furthermore, the safety and reliability required for enhanced IVHS, including Automated Vehicle Control Systems (AVCS) such as electronically controlled platoons [12], requires a fully controllable and (therefore dedicated) radio network with a specific spectrum allocation.

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About the Author

Jean-Paul M.G. Linnartz was born in Heerlen, The Netherlands, in 1961. He received his Ir. (M.Sc. E.E.) degree in Electrical Engineering Cum Laude from Eindhoven University of Technology, The Netherlands, in 1986. During 1987-1988, he was with The Netherlands Organization for Applied Scientific Research, Physics and Electronics Laboratory F.E.L-T.N.O., The Hague, where he worked on UHF propagation and computerized frequency assignment techniques for transportable Radio Relay Networks. From 1988-1991 he was Assistant Professor at Delft University of Technology, where he received his Ph.D. (Cum Laude) on multi-user mobile radio nets in December 1991. In December 1991, he published a short study on improved frequency planning for radio broadcasting, which was quoted by reports and policy notes on the introduction of commercial broadcasting in The Netherlands (Committee Donner and the Dutch Cabinet Minister of Public Health, Welfare and Culture, WVC).

In June 1992, he received the Dutch Veder Prize for his research on traffic aspects in mobile radio networks. Since January 1992, he has been an Assistant Professor in the Department of EECS at the University of California at Berkeley. In February 1993 he published the book "Narrowband Land-Mobile Radio Networks".

His main research activities are in broadcasting, Intelligent Vehicle Highway Systems (IVHS) and indoor wireless communication for multi-media services. During his academic studies he worked as a free-lancer for several radio stations in The Netherlands and Belgium. He is author of a series of magazine articles on the technical aspects radio broadcasting.