On Performance of Multicast Delivery with Fixed WiMAX Telemedicine Networks Using Single-Carrier Modulation

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Abstract—**IEEE 802.16e fixed WiMAX provides a low cost solution for integrated multimedia access networks with a wide bandwidth making it particularly suitable for telemedicine applications. While a wide variety of modulation schemes are suitable for fixed wireless systems, single carrier modulations such as QAM offer advantages such as reduction in power requirements and system complexity compared to multi-carrier transmission systems. In this paper, we analyze the performance of QAM schemes used in a fixed WiMAX system that supports multicast distribution of .real-time traffic for healthcare services by evaluation of system performance on a 10 GHz carrier. Results are presented by comparing the distribution of video data using QPSK and 16-QAM and bandwidth utilization is calculated for continuous data transmission in remote patient monitoring.**

Index Terms— **broadband access, modulation, QAM, telemedicine, WiMAX**

I. Introduction

IEEE 802.16e WiMAX networks are widely used for providing point-to-multipoint network access for fixed locations within a radius of several kilometers due to its design for low cost two-way transmission. Its main advantages include ease of expansion and allowing frequency reuse. Fixed WiMAX provides a means of wireless data distribution at high data rates over a reasonably large area compared to alternative solutions such as wireless local loop (WLL) and wireless cable (multichannel multipoint distribution system), transmission of various types of medical data at frequencies in excess of 10 GHz requires high resolution planning since data packets are vulnerable to burst errors.

Wireless communication systems are affected by channel-induced phenomena such as fading that can significantly impact their performance. In wireless communication systems, a base station modem unit (BMU) is connected to each base station controller (BSC). Its purpose is to convert the digital data to be carried across the radio interface into a format appropriate for transmission over wireless channels. Different equipment manufacturers employ various modulation schemes for their BMU implementations as they have different standards. While the primary concern is making a decision on compromise between cell coverage and data throughput, there is no straightforward answer as to which modulation scheme is best for a wireless network. The optimal tradeoff depends mainly on specific application, for example, systems for life-saving missions would have far more stringent requirements than those for general health assessment. In this paper, we investigate the suitability of using a wireless point-to-multipoint system for distribution of multimedia traffic based on a QAM scheme that is optimized for providing telemedicine services within a local environment [1].

QAM is a very robust type of modulation scheme that provides a high capacity. However, QAM systems are subject to fast Rayleigh fading and time delay spread. Compensation for distortion over Rayleigh fading channels has been studied [2]. In [3], a discussion about the effects of modulated signals transmitted over a fading channel is presented which also includes an outline of a numerical evaluation on such effect [4]. While QAM offers a comparably high number of bits per hertz [5], various QAM modulation schemes have been used by different equipment manufacturers according to some tradeoff between bits per Hertz and bits per unit area coverage. High modulation schemes such as a 128-QAM offers more bits per hertz at the expense of cell size reduction. Numerous research results [6], [7], [8] have been reported with a number of receivers studied illustrating various receiver structures. The receiver structures required for high modulation QAM schemes

Manuscript received October 1, 2009; revised December 23, 2009; accepted January 21, 2010.

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doi:10.4304/jait.1.1.59-65

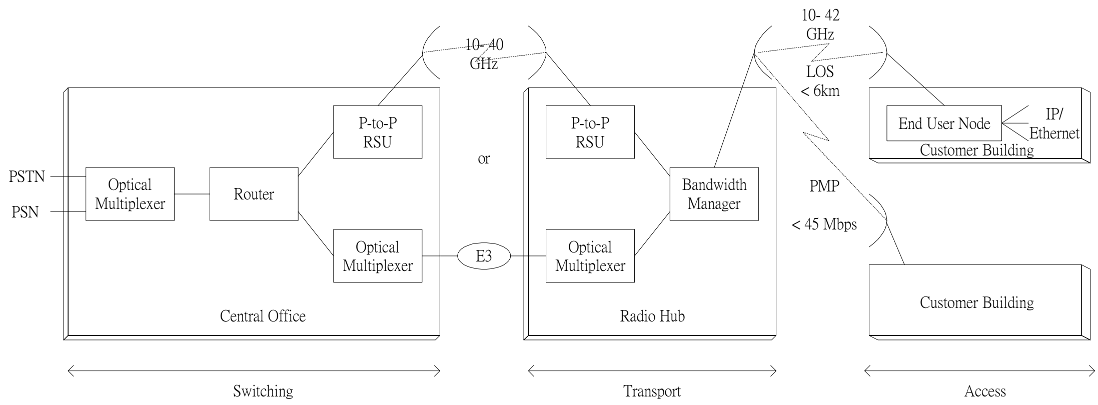

Figure 1. A point-to-multipoint (PMP) network infrastructure

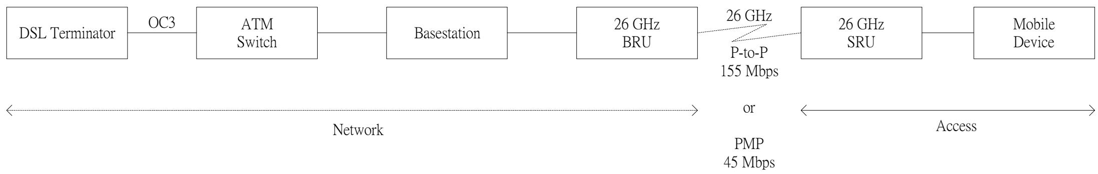

Figure 2. System block diagram

become much more complex than those required for 4 (QPSK) and 16-QAM schemes. Further, an adaptive equalization scheme for a 16-QAM receiver has been proposed [9]. Low modulation QAM schemes are therefore very attractive in terms of costs and size of receiving devices used by consumers. To minimize the effects of cell-to-cell interference, lower modulation schemes are studied.

The use of Orthogonal Frequency Division Multiplexing (OFDM) techniques for multiplexed QAM for a voiceband modem had been studied extensively in the 1980's [10], [11]. More recently, the authors of [12] employed a Coded Orthogonal Frequency Division Multiplexing (COFDM) transmission scheme for an IEEE 802.16 based local multipoint distribution systems (LMDS), leading to further research opportunities for development of modems using an OFDM transmission scheme. The transmission channel is characterized in terms of time and frequency fading predominantly due to movement of receivers relative to the transmitter and multipath propagation, respectively. Although OFDM exhibits certain advantages, single carriers such as variants of QAM offer comparable advantages such as lower power efficient which is particularly suitable for wearable health monitoring receivers; asymmetrical operations is made easier due to simpler transmission circuitry relative to that of reception. Further, high level of narrow-band noise immunity due to inherent capability by use of adaptive equalization makes QAM particularly suitable for transmission over such systems.

We evaluate the system performance by simulating its bit-error probability and coverage. In our experiments, we assumed that the video transmitted does not contain redundancies such as error correction or synchronization characters. It is further assumed that the data traffic volume associated with such redundancies is very much less than that of the video data itself hence the omission would not affect actual system performance.

In this introductory section, we have summarized the advantages of using single-carrier modulation techniques such as QAM and stated the differences between using a high (e.g. M= 128) and a low (e.g. QPSK, M= 4) order M-ary QAM scheme. The remaining sections of this paper are organized as follows. In Section II, we describe the system layout for performance evaluation and the OFDM transmission technique over fading channels is discussed with its performance analyzed in Section III. In Section IV, channel utilization is discussed with analysis on sending multimedia data over the same channel simultaneously. Finally, we conclude the paper in Section V.

II. System Layout

A. Set Up

Position A network has been installed to provide broadband wireless access (BWA) for data delivery through wireless networks across premises of close proximity. While different countries have different spectrum allocations with appropriate regulations, they generally operate in the range of 10 to 66 GHz, and mostly below 40 GHz. In places where radio link availability is greatly affected by persistent heavy rainfall, such as those classified as region-P by ITU, a lower frequency of around 10 GHz is preferred as it is less affected by rain attenuation. Fig. 1 shows the basic operation of a typical network currently set up around the world to provide broadband wireless access delivering a range of services such as video multicasting [13].

The system consists of three main components. It uses the switching and transport portions of the network for connection to the backbone network that processes the incoming multimedia data for distribution over the wireless channel. The system consists of a DSL terminator equipped with an OC3-ATM card used to route IP traffic over ATM connected to the network backbone. The base station that controls the base station radio unit (BRU) consists of a base modem module, a base network module, and a base station controller. The BRU is a self-contained unit with a 45-degree antenna azimuth at 7-degree elevation. The access side, separated by an outdoor wireless channel from the system, evaluates the system performance by studying the received signal. In this network, video data is distributed to make use of wireless internet access which transmits both the video and audio (sound track) signals over wireless broadband channels. Our system is initially intended for stationary reception due to bulkiness of the receiver. However, further research on optimizing for mobile receivers traveling at high speed will be conducted for extending services to ambulances.

Fig. 2 shows a schematic diagram of its operations while keeping the basic elements of the network infrastructure unchanged. The system is designed to provide a range of multimedia services for subscribers through wireless channels. It is optimized for reliable transmission of video with other forms of data such as text and graphics handled at a much lower priority.

The video data is played and distributed to the transmitter through the switching center and up to the wireless backbone network. The BMU handles data traffic between subscribers and the network. In our system, it serves as a modulator that processes the video clip data and sends it via the radio channel to the subscriber receivers. In this system, the BMU does not receive anything from the subscribers as we made an assumption that the data is sent in simplex mode. The envelope of the received signal is given by

$$r(t) = a(t).\sum_{k=1}^{N} s_k(t - kT) \qquad (1)$$

Where s(t) is a signaling pulse and T is the symbol period; N is the total number of paths and k=1 is the line-of-sight (LOS) path. The distortion caused by multipath fading a(t) with linearity [14], [15] is given by:

$$a(t) = a_k(0) + a_k(1)\frac{t - kT}{T} \qquad (2)$$

B. Modulation Scheme

Factors that influence our choice of modulations scheme are:

1. Fading immunity
2. Spectral efficiency
3. Receiver complexity
4. Power efficiency

As discussed in Section I, single-carrier modulation offers better overall compromise for use in many wireless systems. Our work therefore concentrates on comparing lower order QAM schemes such as QPSK and 16-QAM.

System immunity to fading is important to ensure reliable operation under both time and frequency selective fading environments. The effects of fading are discussed in Section II *D*. Spectral efficiency is a measure of data rate per unit bandwidth per unit area given by bps/Hz/m^2. Our aim is to maximize this quantity. Receiver complexity and power efficiency are important considerations, particularly for mobile receivers. For example, power efficiency places a limitation on battery size for mobile receivers.

In essence, higher order M-ary QAM schemes (e.g. M=128) provide higher spectral efficiency at the expense of receiver sensitivity with an increase in modulation level and poor noise immunity. A tradeoff between bps/Hz and transmission quality is therefore an issue in comparison of QAM schemes [16]. We present the result from our study of this tradeoff in Section III.

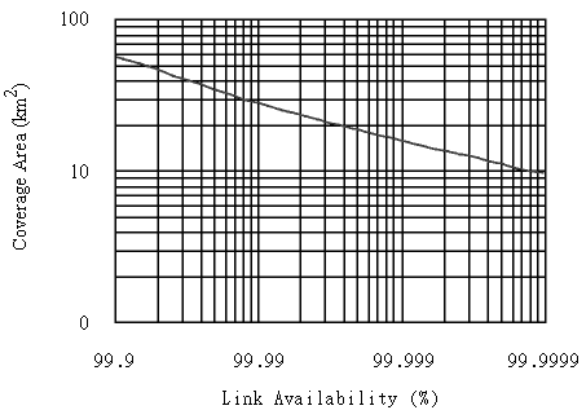

Figure 3. Coverage vs. link availability

C. Link Availability

The effect of path loss reduces signal power over distance. The maximum range that indicates the maximum distance of receivers from the basestation, depends primarily on antenna gain and rainfall statistics. The fade margin can be adjusted for higher link availability. The range covered by a 10 GHz carrier as a function of link availability in percentage of time is illustrated in Fig. 3. The maximum range decreases approximately linearly with a higher availability. The link with 99.99% availability, disabled for no more than

52 minutes per year, offers a range of close to 20km. This is to ensure a bit error rate (BER) performance of 10^{-6} or below. Result shown indicates the maximum link range for a transmission rate of 12 Mbps with 10 GHz carrier with LOS and no rainfall. The range for 99.99% availability is 18 km.

D. Effects of Generalized Fading Channel

In a fixed network environment, the main sources of signal distortion are

1) Multipath fading
2) Frequency selective fading
3) Additive noise

Multipath fading is a collective term used to describe the constructive and destructive superposition of signal components that have taken different paths due to such phenomena as scattering, diffraction and reflection. It therefore amounts to time selective fading. The signal propagation path often has no direct LOS due to physical obstacles between transmitter/receiver antennas. The spectral components of the signal due to frequency selective fading are affected by different fading amplitudes and phase shifts as the signal bandwidth is larger than that of the channel's coherence bandwidth. We consider the effects of generalized channel fading below.

Although in conditions where severe interference and fading make robust carrier recovery become a necessity, the use of OFDM offers good performance in fading and time-variant transmission media [17]. Experiment shows that low-order QAM schemes also provide adequate performance in such situation. A comparison is carried out between the ideal channel and our estimated channel based on assumptions made in [18], [19]. The receiver remains stationary and the bit rate is varied with a carrier frequency of 10 GHz. The channel is defined with the properties

$$pdf\,(R) = \frac{2m^m R^{2m-1}}{R^{2m}} . e^{-m} \qquad (3)$$

where R is a random variable representing the mean-square fading amplitude and

$$m = \frac{R^2}{\mathrm{var}(R^2)} \qquad |m| \geq 0.5$$

There is no fading when m tends to infinity as the pdf becomes an impulse function. The received signal is subjected to additive white Gaussian noise (AWGN), which is assumed to be independent of channel fading. Fig. 4 shows the performance of the receiver with M = 4 and M = 16.

We consider a multilink channel having L independent fading channels as described in [20], the equivalent low-pass impulse response of the time dispersion as the signal propagates through the frequency selective fading channel is given by:

$$h(t) = \sum_{l=1}^{L} a_l . e^{-j\theta} . \delta(t-\tau) \qquad (4)$$

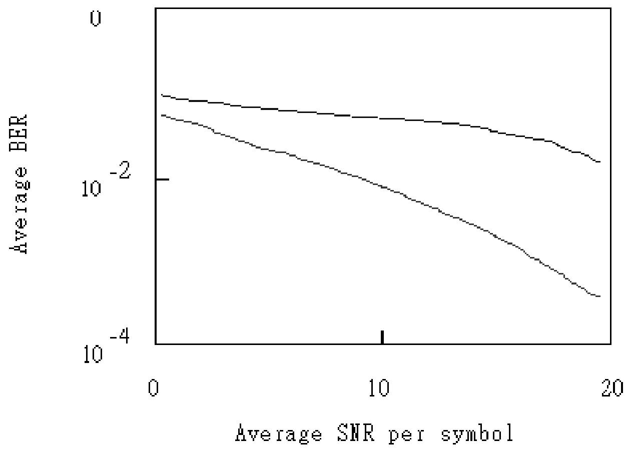

Figure 4. Average BER performance of receiver

where δ(t-τ) is the Dirac delta function, L is the number of paths with the first LOS path being L= 0 and a, θ, and τ represent the amplitude, phase, and magnitude of time delay for each path, respectively.

III. PERFORMANCE ANALYSIS

The purpose of our experiments is to evaluate the E_b / N_o performance of QPSK and 16-QAM for our system under the transmission channel with characteristics described earlier in II *D*. To maintain link availability, the comparison is made at the cut-off point at which the link is no longer available where BER reaches 10^{-6}. Gray encoding with absolute phase coherent detection has been used to improve BER performance. From Fig. 5, QPSK shows a better E_b/N_o performance of 4.3 dB over 16-QAM. The symbol-error rate (SER) of each symbol is different between M = 4 and M = 16. The measured system data rate is 12 Mbps.

Thus, 16-QAM performs noticeably poorer compared to QPSK as shown in Fig. 5. Larger M may offer better performance in number of bits per baud at the expense of increased receiver structure complexity and decrease in BER performance. The system with M = 4 and M = 16 has been compared under different symbol lengths and its performance is shown in Fig. 6. It shows that both 4 and 16-QAM perform very similarly with a constant E_b / N_o value and varying symbol rate.

Results for BER better than 10^{-6} are not presented as the link is considered available and analysis is assumed to be the worst scenario. In actual fact, the difference in performance widens between these modulation schemes as BER decreases further.

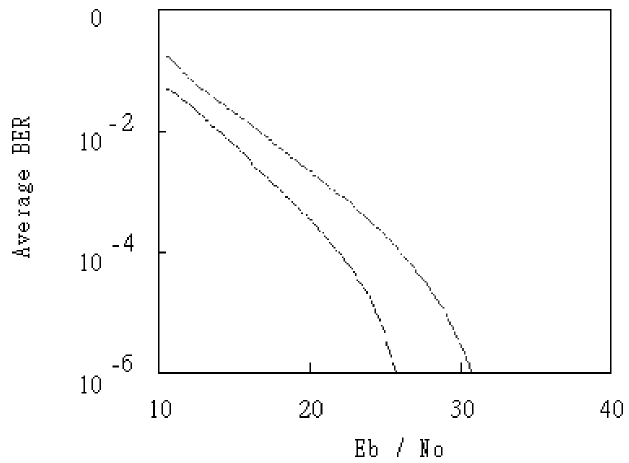

Figure 5. BER comparison between QPSK and 16-QAM

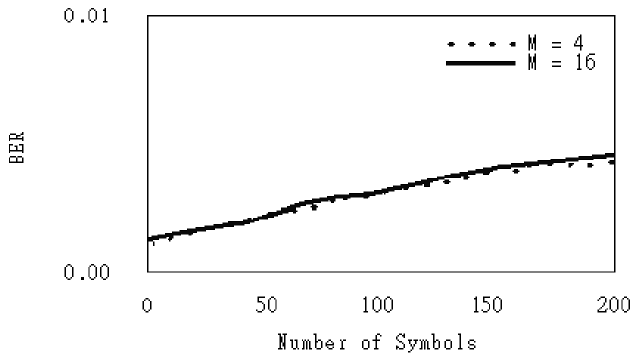

Figure 6. BER vs. data symbol length

Analysis shows that increasing the modulation order from 4 to 16 offers a very slight improvement in bit error rate. However, QPSK offers a slight advantage of simpler receiver structure for the customer modem at the expense of decrease in spectral efficiency by a ratio of 15:3.5. Although it appears that QPSK offers a better compromise than 16-QAM when data symbol length is varied.

IV. Bandwidth Utilization

The system has been set up to measure the suitability of various modulation techniques. With data collected from the actual system, a series of computer simulations are carried out to examine the system's behavior under different contents of audio and video data transmitted. The importance of bandwidth utilization in such network impacts subsequent stages of data processing. Electronic Patient Record (EPR) updating can be affected when the network saturates. The consequential network degradation resulting from saturation can be mitigated by automatic fuzzy ontology algorithms similar to that in [21].

To evaluate the effects of network saturation, we simulate the channel of 9.9 – 10.5 GHz when shared by 5 subscribers, n is defined as the number of subscribers sharing the channel (i.e. n= 5 in our simulation). Each subscriber uses the channel to send different types of data to the BMU. The channel bandwidth is dynamically assigned to utilize the allocated bandwidth to each subscriber. With a mixture of audio (voice) and video (series of images at a fixed rate of 29.7 frames per second) being used as test data, the redundancy bandwidth for audio signal is assumed to be 60% of the time as proposed by [22]. A protocol described in [23] uses redundancy when there is no voice signal transmitted, as detected by voice activation, to transmit other types of signals. With a channel capacity of 50 cells per block for data with overheads neglected, we compute the system throughput as a variation of redundancy bandwidth.

Cell delay is the combined effect of BMU cell waiting time and the actual data transmission time, and the system throughput is measured by the average number of cells transmitted per block of the channel. We assume that video transmission is constant at 29.7 fps with no redundancy, and we further assume that the only data sent is video composed of a mono audio track and pictures only. The system throughput S is given by

$$S = S_A + S_V \tag{5}$$

An assumption that the system only handles data traffic consists of audio and video without other information such as additional synchronization or error correction redundancies has been made so that data handled by the system consists only of audio and video without any other types of data.

For the characteristics of video, its throughput S_V is assumed to be constant which is determined by a function of the transmission rate R_V is given by

$$R_V = P_h.P_v.c.f \tag{6}$$

where P_h and P_v are the number of horizontal and vertical pixels respectively, c is the color depth (e.g. 8 bits for 2^8 or 256 colors) and f is the scan rate in number of frames per second (typically ~30fps for video clips). In our simulation, we tested a video sample of resolution 320 x 240 with 8-bit or 256 colors at 29.7 fps. In this case, R_V is 4.8 Mb/s.

The throughput characteristics of audio S_A is given by

$$S_A = R_A.n.K.\frac{T_t}{T} \tag{7}$$

where $T = T_t + T_i$

The following parameters are used to compute the throughput as an average number of cells transmitted per block of the channel. R_A is the data rate or the bandwidth assigned for the audio (voice) signal. K is the simulation parameter for the audio signal that measures the proportion of time that there is audio data to be sent ($0 \leq K \leq 10$). T is the total transmission time that derives the redundancy bandwidth as in [24] such that T_t and T_i denote the duration of sound being transmitted and the duration when there is no sound (idle), respectively.

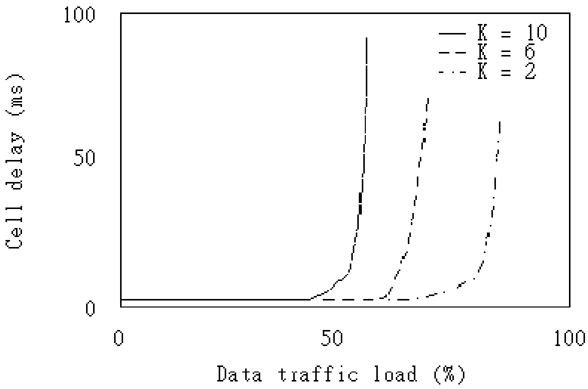

Figure.7. Cell delay characteristics of transmitted data

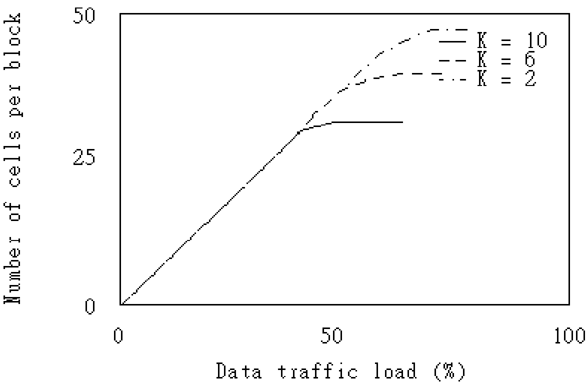

Figure 8. System throughput characteristics

Fig. 7 shows that each cell maintains a low latency and a small cell delay. When more audio data is transmitted (i.e. K increases and R_A also increases), cell delay becomes more severe. Fig. 8 shows the throughput characteristics of the system where its throughput increases with data traffic load linearly until its capacity approaches the maximum available bandwidth. It is noted from Fig. 8 that the channel utilization is affected by T_i as a large T_i decreases channel utilization. So, R_A determines the bandwidth efficiency where it is a close approximation to the system maximum throughput.

V. CONCLUSIONS

We have compared two single-carrier modulation schemes for good compromise between bandwidth efficiency and ease of implementation for use with a fixed WiMAX telemedicine system at a carrier frequency of 10 GHz for distribution of multimedia data over a local area. Although lower modulation schemes offer a reduction in receiver structure complexity at the expense of significant degradation in E_b/N_o performance, this paper leads to the conclusion that a 16-QAM scheme provides optimal compromise between data throughput and cell coverage while provides adequate performance for multicast distribution of video traffic. It is also apparent that the objective of an efficient deployment would be to maximize bandwidth utilization by considering the proportion of time that the audio track is silent.

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- Establishing criteria for paper selection/rejections. The papers can be nominated based on multiple criteria, e.g. rank in review process plus the evaluation from the Session Chairs and the feedback from the Conference attendees.
- Selecting and inviting submissions, arranging review process, making decisions, and carrying out all correspondence with the authors. Authors should be informed the Author Instructions. Usually, the Proceedings manuscripts should be expanded and enhanced.
- Providing us the completed and approved final versions of the papers formatted in the Journal's style, together with all authors' contact information.
- Writing a one- or two-page introductory editorial to be published in the Special Issue.

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