BURST-BY-BURST ADAPTIVE TURBO-CODED OFDM-BASED VIDEO TELEPHONY

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ABSTRACT

A range of Adaptive Orthogonal Frequency Division Multiplex (AOFDM) video systems are proposed for interactive communications over wireless channels. The proposed constant target bitrate subband adaptive OFDM (CTBR-AOFDM) modems can provide a lower BER, than a corresponding conventional OFDM modem. Furthermore, they can achieve an improved video quality performance across a wider range of channel SNRs, requiring typically 2-3dB lower channel Signal-to-Noise Ratios (SNR), than their fixed-mode counterparts.

1. BURST-BY-BURST ADAPTIVE VIDEO TRANSCEIVER

The un-equal 'loading' of the Orthogonal Frequency Division Multiplexing (OFDM) carriers has been suggested by Kalet [1]. This principle has then been further investigated by a number of researchers, invoking it on a time-variant basis [2]. In this contribution an interactive video system is proposed, which employs adaptive OFDM (AOFDM).

1.1. AOFDM Modem Mode Adaptation and Signalling

The proposed duplex AOFDM scheme operates on the following basis:

- *Channel quality estimation* is invoked upon receiving an AOFDM symbol, in order select the best-matching modem mode allocation of the next AOFDM symbol.
- *The decision concerning the modem modes for the next AOFDM symbol* is based on the prediction of the expected channel conditions. Then the transmitter has to select the appropriate modem modes for the groups or subbands of OFDM subcarriers, where the subcarriers were grouped into subbands of identical modem modes, in order reduce the required number of signalling bits.
- *Explicit signalling or blind detection of the modem modes* is used to inform the receiver as to what type of demodulation to invoke.

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1.2. AOFDM Subband BER Estimation

A reliable channel quality metric can devised by calculating the expected overall bit error probability for all available modulation modes $M_n, n = 1 \dots N$ in each sub–band, which is denoted by $\bar{p}_e(n) = 1/N_s \sum_j p_e(\gamma_j, M_n)$, where N_s is the number of subcarriers per subband and γ_j represents the Signal-to-Noise Ratio (SNR) of subband j. The received signal level is assumed to be kept constant by the receiver's Automatic Gain Control (AGC). For each AOFDM sub–band the modem mode having the highest throughput, while exhibiting an estimated BER below the target value is then chosen. While the adaptation granularity is limited to the sub–band width, the channel quality estimation is quite reliable, even in interference-impaired environments.

Against this background in our forthcoming discussions the design trade-offs of turbo-coded Adaptive Orthogonal Frequency Division Multiplex (AOFDM) wideband video transceivers are presented. We will demonstrate that AOFDM provides a convenient framework for adjusting the required target integrity and throughput both with and without turbo channel coding and lends itself to attractive video system construction, provided that a near-instantaneously programmable rate video codec - such as the H.263 scheme highlighted in the next section - can be invoked, which is supported by the adaptive rate-control and packetiser scheme of [4].

1.3. Video Compression and Transmission Aspects

In this study we investigate the transmission of 704x576 pixel Four-times Common Intermediate Format (4CIF) high-resolution video sequences at 30 frames/s using subband-adaptive turbo-coded Orthogonal Frequency Division Multiplex (AOFDM) transceivers. The transceiver can modulate 1, 2 or 4 bits onto each AOFDM sub-carrier, or simply disable transmissions for sub-carriers, which exhibit a high attenuation or phase distortion due to channel impairments.

The H.263 video codec [3] exhibits an impressive compression ratio, although this is achieved at the cost of a high vulnerability to transmission errors, since a run-length coded bitstream is rendered undecodable by a single bit error. In order to mitigate this problem, when the channel codec protecting the video stream is overwhelmed by the transmission errors, we refrain from decoding the corrupted video packet, in order to prevent error propagation

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	BPSK mode	QPSK mode
Packet rate	4687.5 Packets/s	
FFT length	512	
OFDM symbols/packet	3	
OFDM symbol duration	2.6667μs	
OFDM time frame	80 Timeslots = 213μs	
Normalised Doppler frequency, f'_d	1.235×10^{-4}	
OFDM symbol normalised Doppler frequency, F_D	7.41×10^{-2}	
FEC coded bits/packet	1536	3072
FEC-coded video bitrate	7.2Mbps	14.4Mbps
Unprotected Bits/Packet	766	1534
Unprotected bitrate	3.6Mbps	7.2Mbps
Error detection CRC (bits)	16	16
Feedback error flag bits	9	9
Packet header bits/packet	11	12
Effective video bits/packet	730	1497
Effective video bitrate	3.4Mbps	7.0Mbps

Table 1: System parameters for the fixed QPSK and BPSK transceivers, as well as for the corresponding subband-adaptive OFDM (AOFDM) transceivers for Wireless Local Area Networks (WLANs).

through the reconstructed video frame buffer [4]. We found namely that it was more beneficial in video quality terms, if these corrupted video packets were dropped and the reconstructed frame buffer was not updated, until the next video packet replenishing the specific video frame area was received. The associated video performance degradation was found perceptually unobjectionable for packet dropping- or transmission frame error rates (FER) below about 5%. These packet dropping events were signalled to the remote video decoder by superimposing a strongly protected one-bit packet acknowledgement flag on the reverse-direction packet, as outlined in [4]. Turbo error correction codes were used, employing the Logarithmic Maximum Aposteriory (LOG-MAP) decoding technique. The associated codec parameters will be discussed in more depth during our further discourse in the next section.

2. COMPARISON OF SUBBAND-ADAPTIVE OFDM AND FIXED-MODE OFDM

In order to demonstrate the benefits of the proposed subband-adaptive OFDM transceiver, we compare its performance to that of a fixed modulation mode transceiver under identical propagation conditions, while having the same transmission bitrate. The subband-adaptive modem is capable of achieving a low bit error ratio (BER), since it can disable transmissions over low quality sub-carriers and compensate for the lost throughput by invoking a higher-order modulation mode, than that of the fixed-mode transceiver over the high-quality sub-carriers.

Table 1 shows the system parameters for the fixed-mode BPSK and QPSK transceivers, as well as for the corresponding AOFDM transceivers. The system employs constraint length three, half-rate turbo coding, using octal generator polynomials of 5 and 7 as well as random turbo interleavers, where the channel- and turbo-interleaver depth was adjusted for each AOFDM transmission burst, in order to facilitate burst-by-burst or symbol-by-symbol based OFDM demodulation and turbo decoding. Therefore the unprotected bitrate is approximately half the channel coded bitrate. The protected to unprotected video bitrate ratio is not exactly half, since two tailing bits are required to reset the convolutional encoders' memory to their default state in each transmission burst. In both the BPSK and QPSK modes 16-bit Cyclic Redundancy Checking (CRC) is used for error detection and 9 bits are used to encode the reverse link feedback acknowledgement information by simple repetition coding. The packet acknowledgement flag decoding ensues using majority logic decisions. The packetisation [4] requires a small amount of header information added to each transmitted packet, which is 11 and 12 bits per packet for BPSK and QPSK, respectively. The effective or useful video bitrates for the fixed BPSK and QPSK modes are then 3.4 and 7.0 Mbps.

The fixed-mode BPSK and QPSK transceivers are limited to one and two bits per symbol, respectively. By contrast, the proposed AOFDM transceivers operate at the same bitrate, as their corresponding fixed modem mode counterparts, although they can vary their modulation mode on a subband by subband basis between 0, 1, 2 and 4 bits per symbol. Zero bits per symbol implies that transmissions are disabled for the subband concerned.

The "micro-adaptive" nature of the subband-adaptive modem is characterised by Figure 1, portraying at the top a contour plot of the channel Signal-to-Noise Ratio (SNR) for each subcarrier versus time. At the centre and bottom of the figure the modulation mode chosen for each 32-subcarrier subband is shown versus time for the 3.4 and 7.0 Mbps target-rate subband-adaptive modems, respectively. The channel SNR variation versus both time and frequency is also shown in a three-dimensional form in Figure 2, which may be more convenient to visualise. This was recorded for the channel impulse response of Figure 3. It can be seen that when the channel is of high quality – like for example at about frame 1080 – the subband-adaptive modem used the same modulation mode, as the equivalent fixed rate modem in all subcarriers. When the channel is hostile – like around frame 1060 – the subband-adaptive modem used a lower-order modulation mode in some subbands, than the equivalent fixed mode scheme, or in extreme cases disabled transmission for that subband. In order to compensate for the loss of throughput in this subband a higher-order modulation mode was used in the highest quality subbands.

One video packet is transmitted per OFDM symbol, therefore the video packet loss ratio is the same, as the OFDM symbol error ratio. The video packet loss ratio is plotted versus the channel SNR in Figure 4. It is shown in the graph that the subband-adaptive transceivers – or synonymously termed as microscopic-adaptive (μAOFDM), in contrast to OFDM symbol-by-symbol adaptive transceivers – have a lower packet loss ratio (PLR) at the same SNR compared to the fixed modulation mode transceiver. Note in Figure 4 that the subband-adaptive transceivers can operate at lower channel SNRs, than the fixed modem mode transceivers, while maintaining the same required video packet loss ratio. Again, the figure labels the subband-adaptive OFDM transceivers as μAOFDM, implying that the adaptation is not noticeable from the upper layers of the system. A macro-adaption could be applied in addition

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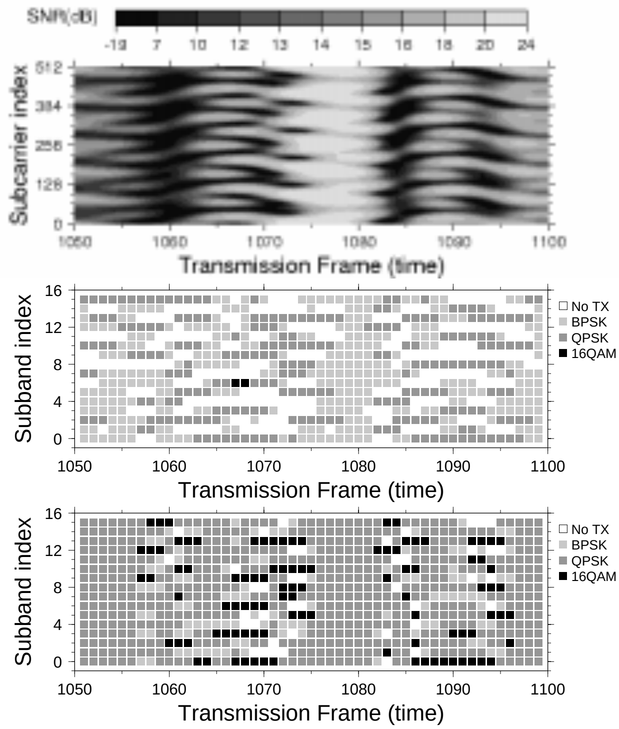

Figure 1: The 'micro-adaptive' nature of the subband-adaptive OFDM modem. The top graph is a contour plot of the channel SNR for all 512 subcarriers versus time. The bottom two graphs show the modulation modes chosen for all 16 32-subcarrier subbands for the same period of time. The middle graph shows the performance of the 3.4Mbps subband-adaptive modem, which operates at the same bitrate as a fixed BPSK modem. The bottom graph represents the 7.0Mbps subband-adaptive modem, which operated at the same bitrate as a fixed QPSK modem. The average channel SNR was 16dB.

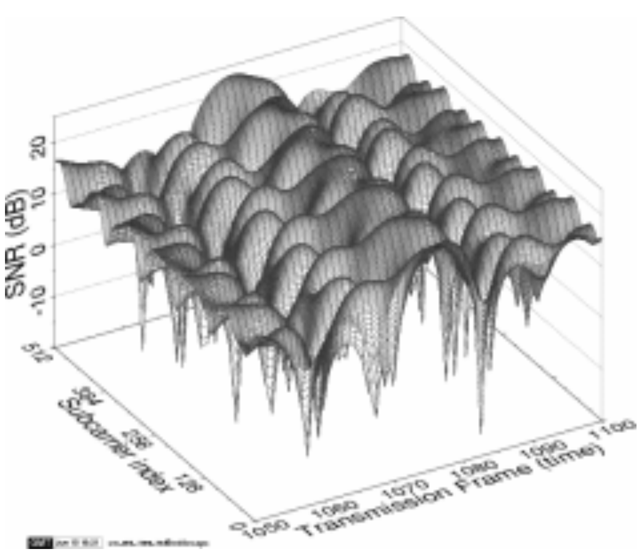

Figure 2: Instantaneous channel SNR for all 512 subcarriers versus time, for an average channel SNR of 16dB over the channel characterised by the channel impulse response (CIR) of Figure 3.

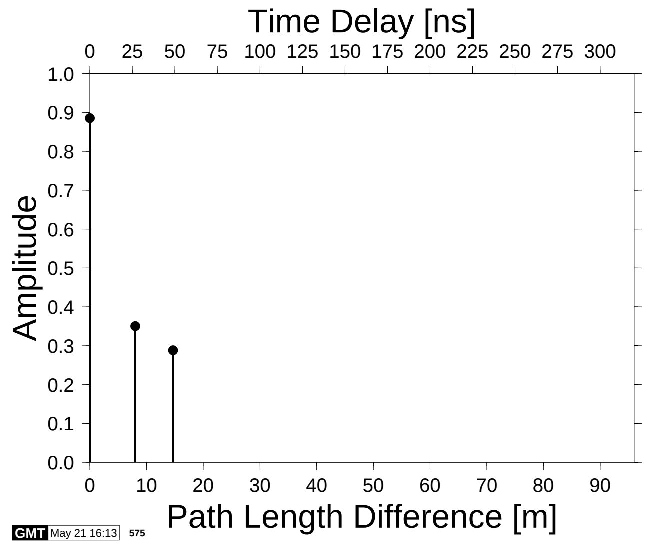

Figure 3: Indoor three-path WATM channel impulse response.

to the microscopic adaption by switching between different target bitrates on an OFDM symbol-by-symbol basis, as the longer-term channel quality improves and degrades. This issue was further investigated in [3].

The figure shows that when the channel quality is high, the throughput bitrate of the fixed and adaptive transceivers is identical. However, as the channel degrades, the loss of packets due to channel impairments results in a lower throughput bitrate. The lower packet loss ratio of the subband-adaptive transceiver results in a higher throughput bitrate, than that of the fixed modulation mode transceiver. Finally, these improved throughput bitrate results translate to the enhanced decoded video quality performance results evaluated in terms of Peak Signal-to-Noise Ratio (PSNR) in Figure 5. Again, for high channel SNRs the performance of the fixed and adaptive OFDM transceivers is identical. However, as the channel quality degrades, the video quality of the subband-adaptive transceiver degrades less dramatically, than that of the corresponding fixed modulation mode transceiver.

3. SUBBAND-ADAPTIVE OFDM TRANSCEIVERS HAVING DIFFERENT TARGET BITRATES

In this section we comparatively study the performance of various μAOFDM systems having different target bitrates. The previously described μAOFDM transceiver of Table 1 exhibited a FEC-coded bitrate of 7.2Mbps, which provided an effective video bitrate of 3.4Mbps. If the video target bitrate is lower than 3.4Mbps, then the system can disable transmission in more of the subcarriers, where the channel quality is low. Such a transceiver would have a lower bit error rate, than the previous BPSK-equivalent μAOFDM transceiver, and therefore could be used at lower average channel SNRs, while maintaining the same bit error ratio target. By contrast, as the target bitrate is increased, the system has to employ higher-order modulation modes in more subcarriers, at the cost of an increased bit-error ratio.

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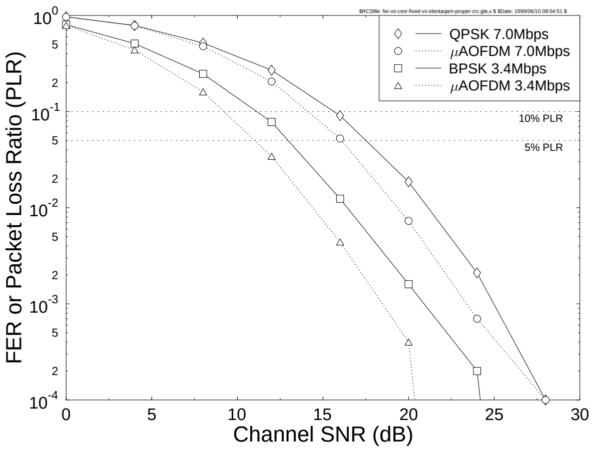

Figure 4: Frame Error Rate (FER) or video packet loss ratio (PLR) versus channel SNR for the BPSK and QPSK fixed modulation mode OFDM transceivers and for the corresponding subband-adaptive μAOFDM transceiver, operating at identical effective video bitrates, namely at 3.4 and 7.0 Mbps, over the channel model of Figure 3 at a normalised Doppler frequency of $F_D = 7.41 \times 10^{-2}$.

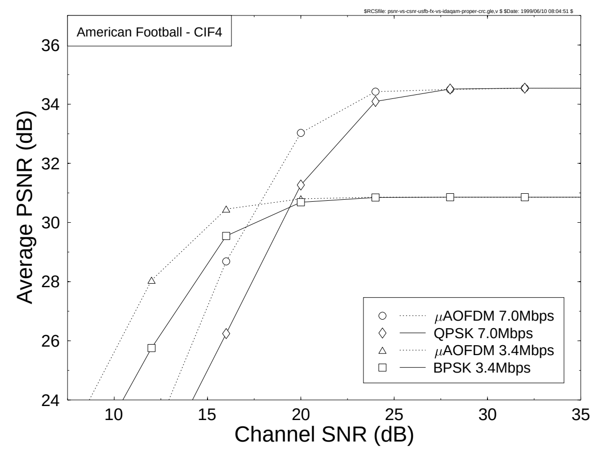

Figure 5: Average video quality expressed in PSNR versus channel SNR for the BPSK and QPSK fixed modulation mode OFDM transceivers and for the corresponding μAOFDM transceiver operating at identical channel SNRs over the channel model of Figure 3 at a normalised Doppler frequency of $F_D = 7.41 \times 10^{-2}$.

Therefore high target bitrate μAOFDM transceivers can only perform within the required bit error ratio constraints at high channel SNRs, while low target bitrate μAOFDM systems can operate at low channel SNRs without inflicting excessive BERs. Therefore a system, which can adjust its target bitrate, as the channel SNR changes, would operate over a wide range of channel SNRs, providing the maximum possible average throughput bitrate, while maintaining the required bit error ratio.

Hence below we provide a performance comparison of various μAOFDM transceivers having four different target bitrates, of which two are equivalent to that of the BPSK and QPSK fixed modulation mode transceivers of Table 1. The system parameters for all four different bitrate modes are summarised in Table 2. The modes having effective video bitrates of 3.4 and 7.0Mbps are equivalent to the bitrates of a fixed BPSK and QPSK mode transceiver, respectively.

Figure 6 shows the Frame Error Rate (FER) or video packet loss ratio (PLR) performance versus channel SNR for the four different target bitrates of Table 2, demonstrating – as expected – that the higher target bitrate modes require higher channel SNRs in order to operate within given PLR constraints. For example, the mode having an effective video bitrate of 9.8Mbps can only operate for channel SNRs in excess of 19dB under the constraint of a maximum PLR of 5%. However, the mode having an effective video bitrate of 3.4Mbps can operate at channel SNRs of 11dB and above, whilst maintaining the same 5% PLR, albeit at about half the throughput bitrate and hence at a lower video quality.

The tradeoffs between video quality and channel SNR for the various target bitrates can be judged from Figure 7, suggesting – as expected – that the higher target bitrates result in a higher video quality, provided that the channel conditions are sufficiently favourable. However, as the channel quality degrades, the video packet loss ratio increases, thereby reducing the throughput bitrate, and hence the associated video quality. The lower target bitrate transceivers operate at an inherently lower video quality, but they are more robust to the prevailing channel conditions and hence can operate at lower channel SNRs, while guaranteeing a video quality, which is essentially unaffected by channel errors. Again, it was found that the perceived video quality became impaired for packet loss ratios in excess of about 5%.

4. CONCLUSIONS

In conclusion, a range of AOFDM video transceivers have been proposed for robust, flexible and low-delay interactive video telephony. In order to minimize the amount of signalling required we divided the OFDM subcarriers into subbands and controlled the modulation modes on a subband-by-subband basis. The proposed constant target bitrate AOFDM modems provided a lower BER, than the corresponding conventional OFDM modems, resulting in an improved video quality.

5. REFERENCES

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[1]For detailed contents please refer to http://www-mobile.ecs.soton.ac.uk

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Packet rate	4687.5 Packets/s			
FFT length	512			
OFDM Symbols/Packet	3			
OFDM Symbol Duration	2.6667μs			
OFDM Time Frame	80 Timeslots = 213μs			
Normalised Doppler frequency, f'_d	1.235×10^{-4}			
OFDM symbol normalised Doppler frequency, F_D	7.41×10^{-2}			
FEC Coded Bits/Packet	858	1536	3072	4272
FEC-coded video bitrate	4.0Mbps	7.2Mbps	14.4Mbps	20.0Mbps
No. of unprotected bits/packet	427	766	1534	2134
Unprotected bitrate	2.0Mbps	3.6Mbps	7.2Mbps	10.0Mbps
No. of CRC bits	16	16	16	16
No. of feedback error flag bits	9	9	9	9
No. of packet header bits/packet	10	11	12	13
Effective video bits/packet	392	730	1497	2096
Effective video bitrate	1.8Mbps	3.4Mbps	7.0Mbps	9.8Mbps
Equivalent modulation mode		BPSK	QPSK	
Minimum channel SNR for 5% PLR (dB)	8.8	11.0	16.1	19.2
Minimum channel SNR for 10% PLR (dB)	7.1	9.2	14.1	17.3

Table 2: System parameters for the four different target bitrates of the various subband-adaptive OFDM (μAOFDM) transceivers

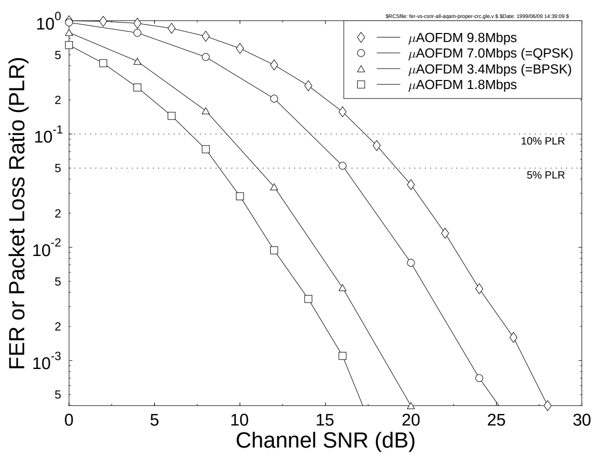

Figure 6: FER or video packet loss ratio (PLR) versus channel SNR for the subband-adaptive OFDM transceivers of Table 2 operating at four different target bitrates, over the channel model of Figure 3 at a normalised Doppler frequency of $F_D = 7.41 \times 10^{-2}$.

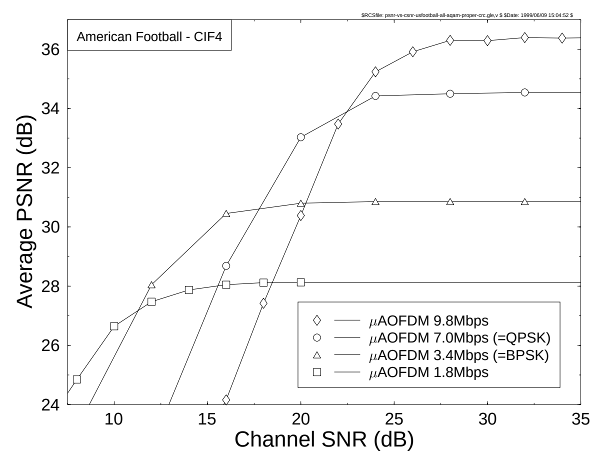

Figure 7: Average video quality expressed in PSNR versus channel SNR for the subband-adaptive OFDM transceivers of Table 2, operating at four different target bitrates, over the channel model of Figure 3 at a normalised Doppler frequency of $F_D = 7.41 \times 10^{-2}$.

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