3GPP TSG RAN WG1#46 **R1-061998**
Tallinn, Estonia
Aug. 28 – Sep. 1, 2006

Source: **Motorola**
Title: **Observations on Alternative L1 Parameters for E-MBMS**
Document for: **Discussion**

1. Introduction

Recently, a set of modified L1 parameters (MLP) have been proposed for E-MBMS broadcast services deployed in single frequency networks (SFN) [1]. The impetus for the new MLP proposals is to optimise broadcast spectral efficiency through a) a re-definition of E-MBMS sub-frame dimensions (to a 2.5ms sub-frame), b) extensions of the cyclic prefix (CP) length to deployments with larger concatenated delay spread (e.g. larger cells size or reduced path loss), and c) a reduction of sub-carrier separation with the goal of reducing CP overhead.

This contribution provides network simulation results comparing the performance of the current reference L1 parameter (RLP) set with the newly proposed MLP sets. We focus on the behaviour of dual-port ('Rx diversity') receiver operation for LTE Cases 3 and 4 – modified for 5MHz operation and for UE velocities of [3,120,350]km/h[1] – in the presence of selected mechanisms for link and receiver SINR loss, but neglecting for now – in the absence of finalised reference symbol (RS) definitions for either the RLP or MLP sets – the important effect of channel estimation error.

2. Impairments and Simulation Parameters

As shown in Table 1 the proposed modified L1 parameter sets (from [1]), denoted MLP1 to MLP5, contain cyclic prefix durations ranging from 13.8us to 91.67us, and sub-carrier separations in the range 1.875-7.5kHz. The 6-symbol (long CP) reference L1 parameter set [2] is also shown in Table 1 under the column 'RLP' and indicates a cyclic prefix duration of 16.67us and sub-carrier separation of 15kHz.

Link impairments considered in this contribution include receiver thermal noise, Doppler induced inter-carrier interference (ICI), the effect of delay spread in excess of the CP length, and implementation losses at the eNB transmitter and UE receiver. A detailed description of each of these elements can be found in the Appendix. However, the critical element of channel estimation error is not yet considered here due to the lack of formally agreed reference pilot structures for RLP or MLP E-MBMS sub-frames.

L1 Parameter Sets	Units	RLP	MLP1	MLP2	MLP3	MLP4	MLP5
Sampling Frequency	MHz	7.68	7.68	7.68	7.68	7.68	7.68
FFT Length		512	1024	1024	1024	2048	4096
Sub-carrier separation	kHz	15	7.5	7.5	7.5	3.75	1.875
#Cyclic Prefix Length	samples	128	256	176	106	352	704
Cyclic Prefix Duration	us	16.7	33.33	22.92	13.8	45.83	91.67
# OFDM Symbols Per Slot	symbols	6	15	16	17	8	4
Symbol Duration	us	83.3	166.67	156.25	147.14	312.5	625
# Used Sub-carriers	sub-carriers	300	600	600	600	1200	2400

Table 1 – Reference (RLP) and modified L1 parameter (MLP) sets.

Note that the *overhead* due the insertion of reference symbols (RS) in every third OFDM symbol starting from the second OFDM symbol of each sub-frame is included for both the RLP and MLP cases. In the case of RLP, this results

[1] *We recognise that 350km/h represents an extreme case, but understand functionality should be maintained in this scenario.*

in primary and secondary reference symbols in the 2nd and 5th OFDM symbol of each sub-frame as suggested in figure 1b) of [3] and reproduced here in Figure 1. This approach is replicated for each of the MLP cases.

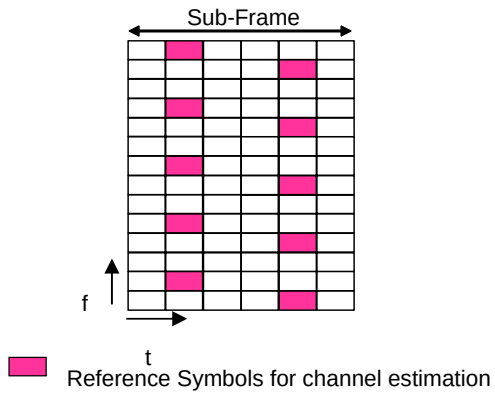

Figure 1 Reference Symbols for channel estimation

All simulations assume dual port UE receiver operation in spatially uncorrelated channels (a 6-ray TU channel was applied on a per-cell basis) using the same modulation and coding schemes and identical pilot overhead. The used modulation coding schemes are suggested in [4] and are listed below in Table 2. Note that the potential benefit of permitting larger codeword lengths to be used in elongated sub-frames (in the MLP case) was not directly assessed, but – given the code word lengths used – this is not expected to have a significant effect on the conclusions. The effect of any applicable outer coding is not reported in the current contribution.

MCS	Number of Coded Bits	Number of Uncoded Bits
QPSK R = 1/4	3200	800
QPSK R = 1/2	3200	1600
QPSK R = 3/4	3200	2400
16QAM R = 1/2	6400	3200
16QAM R = 5/8	6400	4000
16QAM R = 3/4	6400	4800
64QAM R = 5/8	9600	6000
64QAM R = 3/4	9600	7200

Table 2 Modulation and Coding Schemes

3. Simulation Results

The performance criterion used here is coverage (%) vs. spectral efficiency (bps/Hz). A user is defined as in outage if the simulated FER is greater than 1%.

Figure 2, Figure 4 and Figure 6 show results for the modified LTE Case 3 scenario at [3,120,350]km/h, while Figure 3, Figure 5 and Figure 7 show the corresponding data for LTE Case 4. From both sets of figures, it can be seen MLP4 and MLP5 suffer significant coverage loss in high speed environments. Furthermore, while it can be seen that MLP1-3 offer some minor gains in spectral efficiency at the 95% coverage level for modified Case 3. RLP and MLP1-3 perform similarly in modified Case 4 and at the 99% coverage level in Case 3.

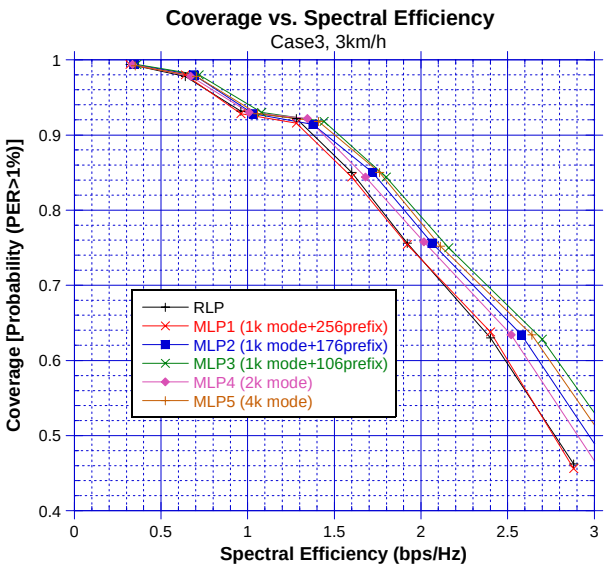

Figure 2 Coverage versus spectral efficiency for Case 3, 3 km/h.

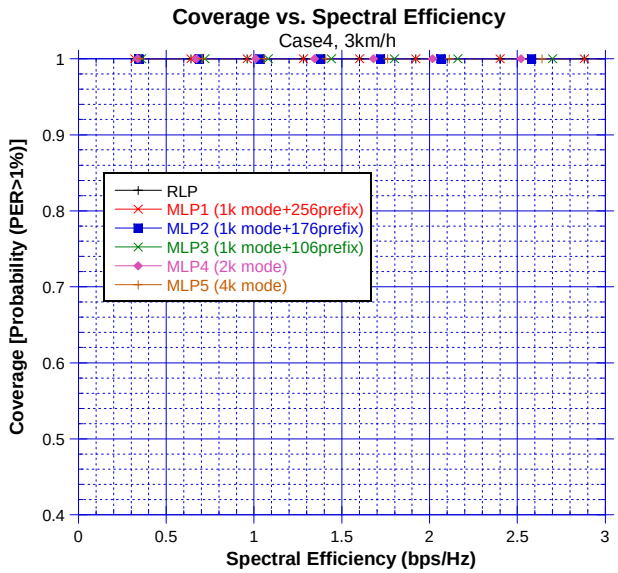

Figure 3 Coverage versus spectral efficiency for Case 4, 3 km/h.

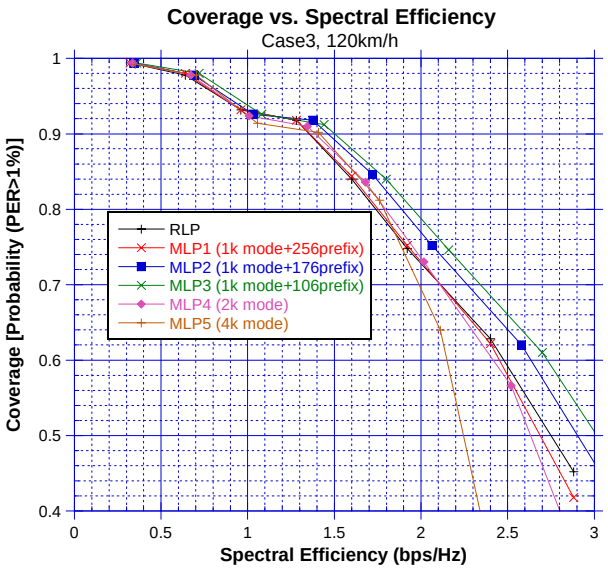

Figure 4 Coverage versus spectral efficiency for Case 3, 120 km/h.

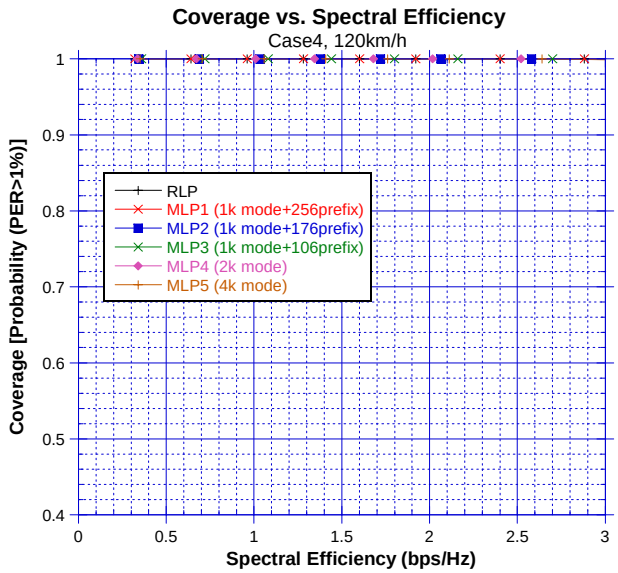

Figure 5 Coverage versus spectral efficiency for Case 4, 120 km/h.

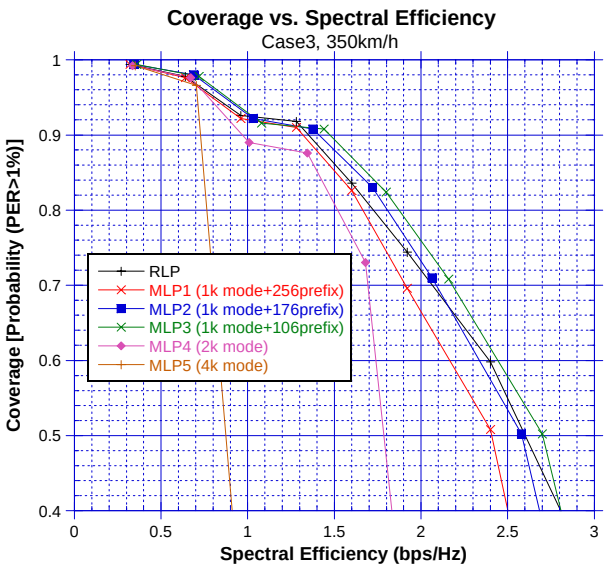

Figure 6 Coverage versus spectral efficiency for Case 3, 350 km/h.

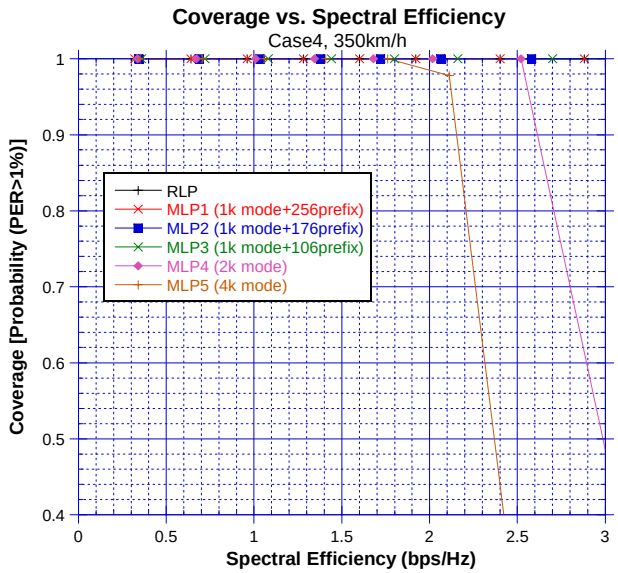

Figure 7 Coverage versus spectral efficiency for Case 4, 350 km/h.

4. Conclusions

Simulation results with receiver impairments and including SINR-limiting effects such as excess delay spread and ICI indicate similar performance for the modified L1 parameters sets outlined in [1] and the current reference link parameter set specified in TS 25.814. Unsurprisingly, the proposed sets MLP4 and MLP5 do not appear robust under extremely high speed conditions. Note, however, that the effect of channel estimation error is not yet included in the results.

While it is possible that other scenarios and/or the inclusion of channel estimation impairments may yield different results, the current simulations do not show a clear benefit from a redefinition of the E-MBMS reference L1 parameter set.

5. References

[1] R1-061847, “Supporting TV broadcast services in LTE (LTE-B)”, Nortel, Cannes, France, June 27-30 2006

[2] 3GPP, TR25.814, “Physical layer aspects for evolved Universal Terrestrial Radio Access (UTRA)”

[3] R1-061189 , NTT DoCoMo, “Investigations on Cell-Common Pilot Channel Structure for MBMS in E-UTRA Downlink”061445, Texas Instruments, “E-MBMS performance: Data Rates and Coverage”

[4] R1-061445, Texas Instruments, “E-MBMS performance: Data Rates and Coverage” ”, Shanghai, China, May 8-12 2006

6. Appendix – SNR Computation With Impairments.

Assuming no impairments, let the observation on the kth sub-carrier at the output of the FFT be given by:

$$y_k = H_k s_k + n_k \tag{1.1}$$

where, $\{H_k\}$ are the frequency-domain coefficients of multi-path fading channel – including shadow fading, path loss and antenna losses and short-term fading process. More precisely,

$$H_k = \sum_{l=0}^{P-1} h_l e^{-j\frac{2\pi kl}{N}} \tag{1.2}$$

where h_l is the lth time-domain channel coefficient and P is the length of the channel impulse response.

Also, $n_k \sim CN(0, N_0)$ is the thermal noise process where N_0 is the one-sided thermal noise power spectral density[2]. Without loss of generality, let $E[|s_k|^2] = 1$.

6.1. Doppler Impairment

Doppler induced inter-carrier interference (ICI) can be accounted for by modifying equation (1.1) as follows:

$$y_k = p_o H_k s_k + n_k + n_d \tag{1.3}$$

where

$$p_o \approx \sqrt{\left(1 - \frac{1}{12}(2\pi f_d T_s)^2\right)} \tag{1.4}$$

and, the variance of the additive ICI n_d is given by

$$E_d \approx \frac{1}{12}(2\pi f_d T_s)^2 \frac{1}{N}\sum_{m=0}^{N-1}|H_m|^2 \tag{1.5}$$

where f_d is the Doppler frequency and T_s is the OFDM symbol duration excluding the cyclic prefix. Hereafter we assume $p_o \approx 1$ which is valid for any reasonable combination of T_s and f_d.

6.2. Link SINR Limit

In practice, the achievable link SNR is limited by transmitter EVM (due to phase noise, DAC quantization, quadrature imbalance, power amplifier non-linearity etc.), adjacent channel ingress, and receiver impairments (including those applicable at the transmitter, plus ADC effects etc.)

Let $(C/I)_{\max}$ be the maximum SNR observed before the demodulator. An additive noise process (say, n_c) is designed to reflect the maximum permitted link SNR, and its variance E_c scales with input signal level as follows,

$$E_c \approx \left(\frac{\frac{1}{N}\sum_{m=0}^{N-1}|H_m|^2}{(C/I)_{\max}}\right) \tag{1.6}$$

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[2] *$CN(0, N_0)$ denotes the complex normal distribution with N_o variance and zero mean.*

Accordingly, the observed symbol can now be written as:

$$y_k = H_k s_k + n_k + n_d + n_c \tag{1.7}$$

In this contribution a value of $(C/I)_{\max} = 20dB$ is assumed.

6.3. Excess Multipath

Applying the excess multipath or insufficient cyclic prefix impairment to (1.7), the observation on the kth sub-carrier be written as:

$$y_k = \tilde{H}_k s_k + n_k + n_d + n_c + n_i \tag{1.8}$$

where n_i is the additional noise added due to the excess multipath impairment and $\tilde{H}_k$ is the modified frequency domain channel coefficient.

Let $c(l)$ be the trapezoidal window for an FFT size of N and cyclic prefix length N_c chips defined as follows:

$$c(l) = \begin{cases} 0 & l < -N \\ (N+l)/N & -N \le l < 0 \\ 1 & 0 \le l < N_c \\ (N+N_c-l)/N & N_c \le l < N+N_c \\ 0 & l \ge N+N_c \end{cases} \tag{1.9}$$

The time domain channel's first arriving ray is assumed to be at $l = 0$. The synchronization point (i.e., the beginning of the FFT window) N_{syn} is obtained by maximizing the energy captured in the window

$$N_{syn} = \max_N \left(\sum_{l=0}^{P-1} c^2 (l-N) |h_l|^2 \right) \tag{1.10}$$

Then E_i, the variance of n_i is given by:

$$E_i = \left(\sum_{l=0}^{P-1} \left(1 - c^2 \left(l - N_{syn}\right)\right) |h_l|^2 \right) \tag{1.11}$$

Also, $\tilde{H}_k$ is given by:

$$\tilde{H}_k = \sum_{l=0}^{P-1} c\left(l - N_{syn}\right) h_l e^{-j\frac{2\pi k (l - N_{syn})}{N}} \tag{1.12}$$

Note: when $P \le N_c$, i.e., the cyclic prefix is sufficient, $E_i = 0$ and the insufficient cyclic prefix coefficient should not be considered.

6.4. Composite SNR

The SNR comprising all impairments and experienced in equation (1.8) is as follows:

$$SNR = \frac{|\tilde{H}|^2}{N_o + E_d + E_c + E_i} \tag{1.13}$$