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Agenda item: OFDM

Source: Lucent Technologies

Title: Proposed Baseline OFDM Systems for Study

Document for: Discussion & Decision

Introduction

In RAN WG1 #27, there was an in-depth discussion on the OFDM SI [1], it was proposed by many companies that a baseline OFDM system should be agreed upon first so that the SI can be carried forward. Here we propose some possible baseline systems which are designed to fit into the current UMTS frame structure.

Design Criterion

Since most companies are interested in using the current IMT2000 band instead of some future spectrum or extra bandwidth. It is reasonable to assume that the performance of the OFDM carrier will be studied first in a 5MHz band in conjunction with either R99 or Rel'5 UTRAN. It is also foreseeable that the symbol duration of the OFDM system should fit into the 0.67 msec time slots currently defined. In order to design the OFDM system properly, the symbol duration should be less than the coherence time and the sub-carrier spacing should be less than the coherence bandwidth. According to [2], assuming the system operates at 2GHz band and the UE speed ranges from 0km/hr to 400km/hr, we obtain the following table for coherence time under different definitions for coherence time and UE speeds,

UE Speed	Coherence Time T_c	
	Definition 1: $T_c = 0.179/f_d$	Definition 2: $T_c = 0.423/f_d$
3 km/hr	33.22 msec	76.14 msec
30 km/hr	3322 usec	7614 usec
100 km/hr	967 usec	2284 usec
120 km/hr	805.5 usec	1903.5 usec
400 km/hr	242 usec	571 usec

Table 1. UE speed vs. Coherence Time at 2GHz carrier frequency.

The sub-carrier spacing should be large enough to provide robustness against frequency offset and phase noise, but it also has to be small enough such that each sub-carrier experiences flat fading. Normally, the tone (or sub-carrier) spacing can be selected by first fixing a maximum delay spread from all possible channel conditions, calculating the coherence bandwidth and then using it as an upper bound for the sub-carrier spacing. From [3], the Pedestrian A, Pedestrian B, and Vehicular A channel model, have maximum delay spread at 410ns, 3.7usec and 2.5usec, respectively. We suggest that a maximum delay spread of 10 usec be considered for the design of the OFDM system. The 10-usec suggestion takes into account only the cyclic prefix, some extra guard time should be added to allow some ramp-up and ramp-down period for the power amplifier. Time domain filtering maybe necessary to avoid the spurious effect due to the possible sudden transition between the consecutive OFDM symbols. In order to reduce the out of band emissions effectively, a raise cosine window with roll-off factor equal to one should be allowed. Note that it is observed that in a simulcast environment, the signal coming from the other cell is most likely the dominant multi-path which has longer delay than the non-simulcast signal. Therefore, larger delay spread should be considered if multicast and simulcast services are of interest. Table 2 shows some parameters for coherence bandwidth based on various definitions stated in [2].

Max. Channel Time Dispersion $\sigma_{d,max}$	Coherence Bandwidth B_c	
	Definition 1: 0.9 correlation BW $B_c = 1/(50^*\sigma_{d,max})$	Definition 2 : 0.5 correlation BW $B_c = 1/(5^*\sigma_{d,max})$
2.5 usec	8 kHz	80 kHz
5 usec	4 kHz	40 kHz
10 usec	2 kHz	20 kHz
40 usec	0.4 kHz	5 kHz

Table 2. Max. Delay Spread vs. Coherence Bandwidth.

FFT Size

From Table 1., assuming the nominal UE speed is less than 120 km/hr, we can choose the OFDM symbol duration up to 805.5 usec as long as it does not violate the coherence bandwidth dictated by Table 2. To keep the time domain overhead, i.e. the cyclic prefix and guard time, small, it is desirable to limit the amount of time overhead to be less than 10% of the time domain symbol duration. Table 3. summarized the number of sub-carried allowed under 5, 10, and 15% time domain overhead (T_g) assumptions, and the number of FFT points required to implement it. Note that T_u is the useful/signal part of the symbol, and T_g is the guard time. The number sub-carriers can be supported in a 5MHz bandwidth is given by $\lfloor 5MHz/T_u \rfloor$, where the numbers are rounded to the nearest integers from below.

No. Sym/TS	OFDM Symbol period (T_u+T_g)	No of tones w/ 5% time overhead	No. of FFT points	No of tones w/ 10% time overhead	No. of FFT points	No of tones w/ 15% time overhead	No. of FFT points
1	667 usec	3166	4096	3000	4096	2833	4096
2	333 usec	1583	2048	1500	2048	1416	2048
3	222 usec	1055	2048	1000	1024	944	1024
4	167 usec	791	1024	750	1024	708	1024
5	133 usec	644	1024	600	1024	566	1024

6	111 usec	527	1024	500	512	472	512
7	95.2 usec	452	512	428	512	404	512
8	83.3 usec	395	512	375	512	354	512
9	74.1 usec	351	512	333	512	314	512
10	66.7 usec	316	512	300	512	283	512
11	60.6 usec	287	512	272	512	257	512
12	55.6 usec	263	512	250	256	236	256
13	51.3 usec	243	256	230	256	217	256
14	47.6 usec	226	256	214	256	202	256
15	44.4 usec	211	256	200	256	188	256
16	41.7 usec	197	256	187	256	177	256

Table 3. Number of Symbols per Time slot vs. Number of possible sub-carriers over 5MHz bandwidth vs. Number of FFT points needed

It can be seen that with less than 10% time overhead, the most efficient choices of the FFT operations are 1024, 512, and 256 at 3, 6, and 12 symbols per time slot. To guarantee the highest data rate, all 1024, 512 or 256 sub-carriers should be used to transmit. The smaller the number of sub-carriers is, the wider the sub-carrier spacing becomes which leads to robustness against frequency offset and phase noise.

Frequency Guard Band

In Figure 1., we show the spectrum emission mask defined in [4] for UMTS together with the spectrum of a time domain pulse shaping filter which is suitable for WCDMA transmission. The filter is a raise cosine filter with a roll off factor of 0.22. Similarly, in Figure 2., we show the same mask with only the positive frequencies, together with the spectrum of a un-filtered OFDM frequency carriers. To obtain the OFDM spectrum, we assume that there are a total of 1024 sub-carriers, each is transmitting a modulated symbol 1, and the sub-carrier spacing is equal to 4.8kHz. Unlike what's shown in Figure 1 for the WCDMA, Figure 2 shows that the spectrum of the OFDM sub-carriers rolls off very quickly at the edge of the frequency band. Hence a tighter frequency guard band than the WCDMA should be permitted in OFDM.

In the remaining of the section, we shall describe a system with 222 usec symbol duration using a 1024-point FFT and assuming all 1024 sub-carriers are transmitting. In this case, the sub-carrier spacing can be any value between 4.80 kHz and 4.87 kHz. If we assume the sub-carrier spacing to be 4.8 kHz, we have a useful signal period (T_u) of 208.33 usec and a guard time (T_g) of 13.889 usec. The total system bandwidth is then 4.9152 MHz, which leaves a frequency guard band of 42.4 kHz on each side of the 5 MHz band. If we choose a sub-carrier spacing of 4.85 kHz, we have a 16.8 kHz guard band on each side of the 5 MHz band and a 16 usec guard time. The optimal value of sub-carrier spacing can be determined later after the adjacent channel emission requirement has been agreed. Right now, since both design satisfy the criterion laid out in the previous sections, we are comfortable with either design.

If in the end, larger frequency guard band is needed due to windowing, adjacent interference reduction, etc., we can easily widen the guard band by silence a few sub-carriers that are at the edge of the frequency band.

Proposed Baseline System

Based on the above discussion, we would like propose a baseline system with multiple configurations suitable for different channel conditions. Some benefit of having multiple configurations are:

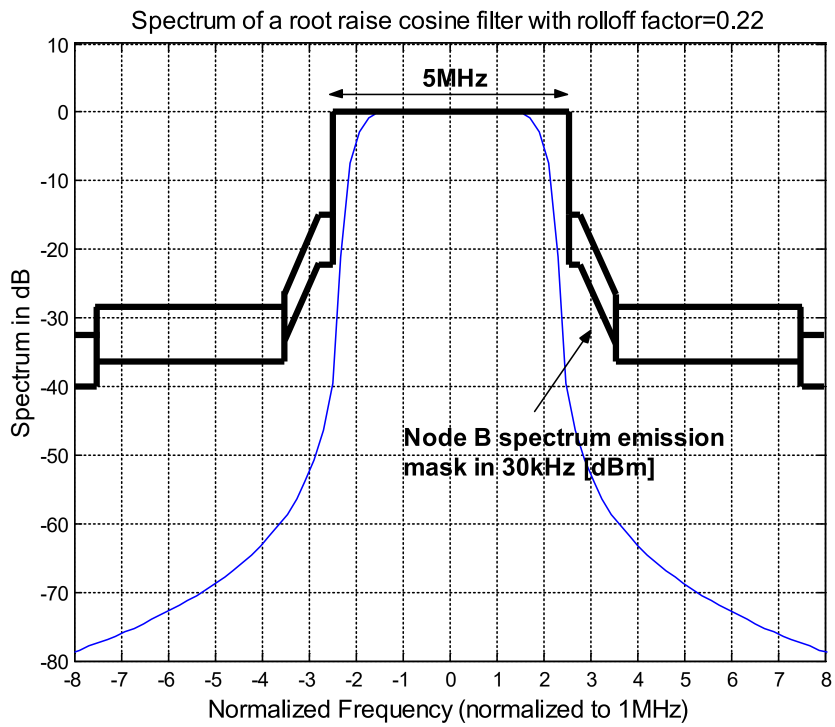

Figure 1. UMTS spectrum emission mask and the spectrum of a square root raise cosine WCDMA pulse shaping filter.

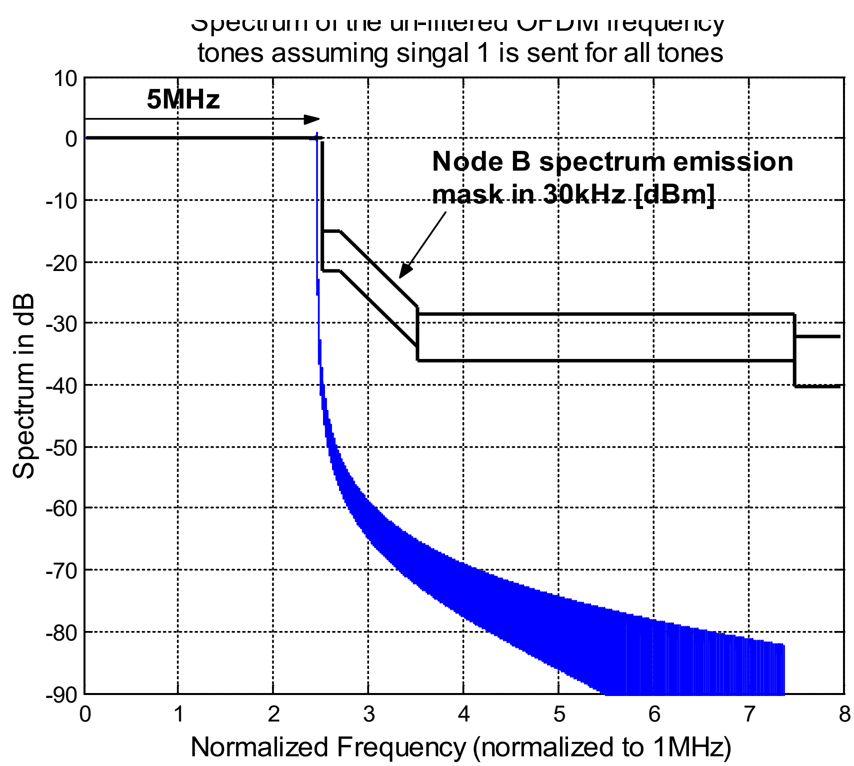

Figure 2. UMTS spectrum emission mask and the OFDM frequency spectrum assuming 1024, 4.8kHz wide sub-carriers with the sinc frequency pulse without any time domain windowing.

(1) To allow shorter symbol durations when the multipath is less severe, this would result in wider sub-carrier spacing which would make the system more immune to frequency offset

(2) To use shorter symbol duration which makes the system less susceptible to high Doppler and hence reduces the ICI

(3) To use smaller size FFT which lowers the power consumption and the UE complexity.

These multiple configurations have the same sampling frequency, which will simplify the receiver implementation while allowing UE to switch smoothly to different configurations supported by the Node Bs in different multipath environments.

Table 4. summarizes the parameters for the baseline OFDM system and the three reference configurations. Configuration 1 has 12 symbols in one 0.67 msec time slot using a 256-point FFT; Configuration 2 has 6 symbols in one time slot with a 512-point FFT; Configuration 3 has 3 symbols and uses a 1024-point FFT. In all configurations, the sampling period is 0.20345025 usec. The length of the cyclic prefix, which is directly proportional to the system's resilience to multipath interference, is different for each configuration. The suitable deployment environment for each configuration is summarized in row two. Figure 3. shows the OFDM symbol structure under different configurations.

System Parameters	Configuration 1	Configuration 2	Configuration 3
Suitable deployment environment	Indoor, Pedestrian A	Vehicular A	Pedestrian B
Symbol per 0.67 msec time slot	12	6	3
Number of FFT points	256	512	1024
Number of sub-carriers	256	512	1024
OFDM Symbol period (usec)	55.6	111	222
Sub-carrier spacing (kHz)	19.2	9.6	4.8
Guard band on each side of the 5MHz band (kHz)	42.4	42.4	42.4
Sampling period (usec)	0.20345025	0.20345025	0.20345025
Guard time $T_g = T_{prefix} + T_{postfix}$ (samples/usec)	17/3.46	34/6.92	68/13.8
Cyclic prefix length (samples/usec)	5/1.017252604	16/3.255204	50/10.17252604
Power amplifier ramp-up and ramp-down period (samples)	6 samples each	9 samples each	9 samples each

Table 4. Parameters for baseline OFDM systems

Clock Rate

In [5], it is mentioned that the clock rate should be selected to be an integer multiple of the WCDMA chip rate (3.84Mcps). While we also have considered the importance of the sampling frequency, our feeling is that: the increase in implementation cost is minor as long as the sampling frequency is a rational multiple of the oscillator frequency. The division of an integer is a simple feedback loop in the VCO circuit. The rational multiple rule ensures the stability of the output of the VCO. Furthermore, even though the WCDMA chip rate is 3.84 Mcps, a manufacturer, for whatever reason, may opt to use an oscillation with a much higher frequency. For example, a system implementing 8-time oversampling will use an Oscillator at 30.72 MHz. In our proposed baseline system, we have proposed a sampling frequency of 4.9152MHz which is (32/25) larger than the WCDMA chip rate. Based on our experience, a frequency division of 25 is a common practice in circuit design. This choice of sampling frequency is also compatible with the WCDMA sampling rate with up to 32-time oversampling. A dual mode system operating at 30.72 MHz sampling rate can choose to implement a (4/25) circuit for the OFMD carrier with minor increase in complexity.

Since the increase in complexity from a 1024-point FFT to a 1200-point FFT is at least 38% [5], we believe that the cost in implementing a simple feedback loop in the VCO is much simpler and justified solution.

Supported Data rates

The raw bit rates of the baseline system can be computed without taking into account any coding or any kinds of signaling overhead. More precise data rate can be computed once the modulation, code rate, pilot-to-data ratio, and the signaling overhead is assumed. Table 5 and 6 summarize the possible data rates of the three reference configurations under different modulations with a pilot-to-data ratio equal to 10% and 15%, respectively. Note that these data rates does not take into account the signaling overheads which is yet to be determined. Also note that the highest data rate with 16QAM is about the same as Rel'5 HSDPA.

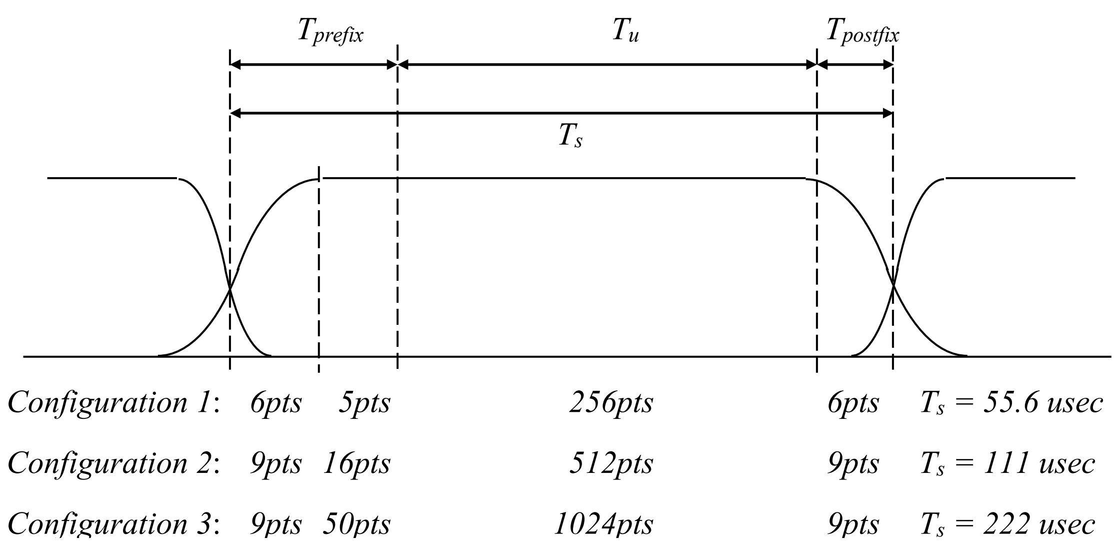

Figure 3. The OFDM Symbol

Code rate	Modulation		
	QPSK	16QAM	64QAM
1/4	2.0736 Mbps	4.1472 Mbps	6.2208 Mbps
1/2	4.1472 Mbps	8.2944 Mbps	12.4416 Mbps
3/4	6.2208 Mbps	12.4416 Mbps	18.6624 Mbps
1	8.2944 Mbps	16.5888 Mbps	24.8832 Mbps

Table 5. Some examples of the achievable data rate using different modulations with the pilot-to-data ratio + signaling overhead equal to 10%

Code rate	Modulation		
	QPSK	16QAM	64QAM
1/4	1.9584 Mbps	3.9168 Mbps	5.8752 Mbps
1/2	3.9168 Mbps	7.8336 Mbps	11.7504 Mbps
3/4	5.8752 Mbps	11.7504 Mbps	17.6256 Mbps
1	7.8336 Mbps	15.6672 Mbps	23.5008 Mbps

Table 6. Some examples of the achievable data rate using different modulations with the pilot-to-data ratio + signaling overhead equal to 15%

Conclusion

We have suggested an OFDM system with multiple configurations that can be deployed in different environments. The system is designed to fit into the current UMTS time slot structure. If agreed upon, the system will be used as a baseline for future OFDM study.

References

[1] R1-02-0932, Assumptions and objectives for "Analysis of OFDM in UTRAN enhancement" Study Item, Nortel Networks

[2] Theodore S. Rappaport, "Wireless Communications Principles and Practice," 1996, Prentice Hall.

[3] 3GPP TR 25.890 "High Speed Downlink Packet Access: UE Radio Transmission and Reception"

[4] 3GPP "Technical Specification Group Radio Access Networks UTRA (BS) FDD: Radio Transmission and Reception," TS25.104 v3.2.0, March 2000.

[5] R1-02-1222, Reference OFDM Physical Layer Configuration, Nortel Networks, 3GPP TSG RAN1 Meeting #28bis, Espoo, Finland, October 8-9, 2002. Associated slides R1-02-1223.