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Agenda Item:

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Title: **Performance study of Uplink Synchronous Transmission Scheme (USTS)**

Document for: **Discussion**

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1. Introduction

Uplink Synchronous Transmission Scheme (USTS) is an alternative technology applicable for low mobility terminals, especially in indoor and WLL-like environments. USTS can reduce uplink intra-cell interference by means of making a cell receive orthogonalized signals from UEs. And accordingly, USTS is expected to yield better performance. This feature is intended to support uplink synchronous transmission with low overhead, good capacity characteristics, and minimal impact on hardware and software resources at the UE and in the UTRAN.

In a USTS mode, less interference comes from other users owing to orthogonality property among UEs in a same cell, which is expected to yield good performance. First, the performance is mathematically investigated in terms of E_b / I_o gain and the number of supportable users. Uniform delay profile with L resolvable paths and ideal Rake combing with L fingers are assumed. With a same E_b / I_o value, two times larger number of users can be accommodated if USTS is adopted for a single cell system in case of L =2.

Section 3 introduces some simulation results to show the signal-to-interference ratio (SIR) gain comparison between USTS and non-USTS modes, the effect of time misalignment (the effect of timing control resolution), the timing control rate, and the effect of TAB error.

2. Mathematical analysis

The purpose of this section is to show some simple equations in a special situation for

- ✓ Performance gain of USTS
- ✓ Relation between E_b / I_o (SIR) and capacity
- ✓ Effect of fast TPC.

2.1. System modelling

- ✓ Single cell system
- ✓ N users in communication
- ✓ Uniform delay profile with L paths
- ✓ Number of Rake finger = L (ideal combining)
- ✓ S_i : Received signal power at Node B of i -th user after compensating slow fading
- ✓ a_{ij} : Squared path gain of j -th path of i -th user

$$E\left[a_{ij}\right] = 1/L \quad \text{for all } i, j \tag{2.1}$$

$$\sum_{j=0}^{L-1} E\left[a_{ij}\right] = 1 \tag{2.2}$$

- ✓ $S_i a_{ij}$: Received signal power at Node B of i -th user along j -th path

2.2. Case I : All multipaths are aligned

2.2.1. Without fast TPC

The sum of interference from other users is well approximated as a Guassian noise, when observed over a short-term time interval (which is defined as a time interval enough to remove those due to shadowing), due to central limit theorem for a large number of users. So this approximation is used herein and thus, the transmission quality can be evaluated using the signal energy per information bit-to-short term average interference plus background noise power spectrum density ratio E_b / I_o.

For non-USTS, interference comes from all other users and other paths. E_b / I_o of i-th user along j-th path can be expressed as

$$\left(\frac{E_b}{I_o}\right)_{ij} \triangleq \frac{GS_i a_{ij}}{E\left[\sum_{l=0}^{N-1}\sum_{m=0}^{L-1} S_l a_{lm} - S_i a_{ij}\right] + N_o} \approx \frac{Ga_{ij}}{E\left[\sum_{l=0}^{N-1}\sum_{m=0}^{L-1} a_{lm} - a_{ij}\right]} \tag{2.3}$$

where $S_i = S_j$ for all j for single traffic type. The approximation comes from dropping N_o term in the denominator. Now E_b / I_o of i-th user can be given by

$$\left(\frac{E_b}{I_o}\right)_i \approx \sum_{j=0}^{L-1}\left(\frac{E_b}{I_o}\right)_{ij} = \frac{GX_i}{E\left[\sum_{l=0}^{N-1}\sum_{m=0}^{L-1} a_{lm} - a_{ij}\right]} = \frac{GLX_i}{NL-1} \approx \frac{G}{N} X_i, \tag{2.4}$$

where $X_i = a_{i0} + \ldots + a_{iL-1}$ and the last approximation is for large *N*.
For USTS, there is no interference from the same path of other users. And (2.3) and (2.4) can be modified as

$$\left(\frac{E_b}{I_o}\right)_{ij} \triangleq \frac{GS_i a_{ij}}{E\left[\sum_{l=0}^{N-1}\sum_{m\neq j} S_l a_{lm}\right] + N_o} \approx \frac{Ga_{ij}}{E\left[\sum_{l=0}^{N-1}\sum_{m\neq j} a_{lm}\right]} \tag{2.5}$$

and

$$\left(\frac{E_b}{I_o}\right)_i \approx \frac{GX_i}{E\left[\sum_{l=0}^{N-1}\sum_{m\neq j} a_{lm}\right]} = \frac{GLX_i}{N(L-1)}. \tag{2.6}$$

2.2.2. After fast TPC (ideal)

Through fast TPC, the signal power is adjusted so that fast fading is compensated after Rake combining and accordingly, the above equations are modified as follows.
For non-USTS,

$$\left(\frac{E_b}{I_o}\right)_i = \sum_{j=0}^{L-1}\left(\frac{E_b}{I_o}\right)_{ij} \approx \sum_{j=0}^{L-1}\frac{G\frac{a_{ij}}{X_i}}{E\left[\sum_{l=0}^{N-1}\sum_{m=0}^{L-1}\frac{a_{lm}}{X_l} - \frac{a_{ij}}{X_i}\right]} = \frac{GL}{NL-1} \approx \frac{G}{N}, \tag{2.7}$$

where the last approximation is for large *N*.
For USTS,

$$\left(\frac{E_b}{I_o}\right)_i \approx \sum_{j=0}^{L-1} \frac{G\dfrac{a_{ij}}{X_i}}{\sum_{l=0}^{N-1}\sum_{m\neq j} E\left[\dfrac{a_{lm}}{X_l}\right]} = \frac{GL}{N(L-1)}. \tag{2.8}$$

All the above equations are applied only for $L \geq 2$. When L =1, the capacity comes to zero due to power rise induced by fast TPC ($E[1/X_i]$ becomes infinite in case of L =1).

2.2.3. Discussion

1 For slowly moving UEs, fast TPC can be assumed to be perfect just like Section 2.2.2

2 Gain in E_b / I_o (dB) becomes

$$10\log\left(\frac{NL-1}{N(L-1)}\right) \approx 10\log\left(\frac{L}{L-1}\right) \text{ for large } N. \tag{2.9}$$

3 If the required E_b / I_o for both cases are same, then $L/(L-1)$ times larger number of users can be accommodated in USTS mode compared to non-USTS mode for large number of users. For example, 100 % and 50 % more users when L =2 and 3, respectively.

4 If average E_b / I_o value is concerned in case without fast TPC, the comparative results between USTS and non-USTS modes are the same as in case with fast TPC (ideal) because of $E[X_i] = 1$ for all i

5 By using USTS, less interference comes from other UEs and therefore, larger E_b / I_o and less signal power can be achieved. Hence, better link budget and higher capacity can be expected.

6 USTS can yield better performance as the number of resolvable multipaths decreases.

7 In most cases, the first two multipaths have most of signal power on average, which well corresponds to the case of L =2.

8 In an indoor environment, the other cell interference effect is relatively small compared to other environments. This case is well suited for USTS because at this point handoff is not supported in USTS mode.

9 We can easily estimate the gain in a multiple cell system, referring to e.g., the ratio of other cell interference to own cell interference. The multiple cell gain is expected to be smaller than single cell gain but in some environments such as indoor, the gain is still high.

2.3. Case II : Only the first significant paths are aligned

According to the usual channel models, the delays between the first path and other paths are constant. However, this model is just a model and in a real environment, it may be difficult to align all the paths. For USTS, only the first significant paths get orthogonality and the other paths are just like non-USTS mode. Therefore, (2.5) is rewritten as

$$\left(\frac{E_b}{I_o}\right)_{ij} \approx \begin{cases} \dfrac{Ga_{i0}}{E\left[\sum_{l=0}^{N-1}\sum_{m\neq 0} a_{lm}\right]}, & j = 0 \\[2ex] \dfrac{Ga_{ij}}{E\left[\sum_{l=0}^{N-1}\sum_{m=0}^{L-1} a_{lm} - a_{ij}\right]}, & j \neq 0 \end{cases} \tag{2.10}$$

For large N, $(E_b / I_o)_i$ is simplified as

$$\left(\frac{E_b}{I_o}\right)_i \approx \frac{G}{N}\left(X_i + \frac{a_{i0}}{(L-1)}\right). \tag{2.11}$$

Similarly, $(E_b / I_o)_i$ after fast TPC can be obtained by

$$\left(\frac{E_b}{I_o}\right)_i \approx \frac{G}{N}\left(1+\frac{1}{(L-1)}\frac{a_{i0}}{X_i}\right). \tag{2.12}$$

Comparing (2.11) and (2.12) to (2.4) and (2.7) for large N, the second terms are added, which reflects the effect of the orthogonality of the first significant paths. This result can be considered as the worst case performance of USTS because all multipaths but the first significant ones are not aligned at all. These two cases will be considered in the following simulations. Also investigated is the imperfect alignment of the first significant paths. If exponential profile is considered, the performance of USTS becomes better because more power is carried along the first path on average and the average power decays exponetially as the path index increases and accordingly, the effect of the first path is dominant compared to other paths.

3. Simulation analysis

3.1 Simulation environments

One of JTC (Joint Technical Committee) channel models, outdoor urban high-rise channel model is applied in our simulation [Joint Technical Committee (Air) Standards Contribution, JTC(air)/94.09.23-065R6]. This channel model consists of 6 paths whose relative delays are 0, 200, 800, 1200, 2300 and 3700nsec and corresponding average power of 0, -0.9, -4.9, -8.4, -7.8 and -23.9 dB, respectively. RAKE receiver performs maximal-ratio combining and uses 3 paths within the span of the delay spread in channel model. We set Doppler frequency at 10 Hz(about 5.6km/hour at 1.9 Ghz) to model the pedestrian environment.

3.2 SIR comparison

Fig. 3.1 shows the Signal to Interference Ratio(SIR) according to the number of users where the curves corresponds to asynchronous, synchronous and misaligned synchronous transmission. In synchronous transmission, both the 128-ary Walsh orthogonal code which is unique to each user and the extended maximal code of length 2^{14} are employed. In case of asynchronous transmission, extended maximal code of length 2^{32} is employed instead of Walsh code. The curve denoted by (1/8,10) chip represents SIR when synchronization of the first significant path is assumed to be carried out within 1/8 of a chip duration and multipath components are aligned within 10 chips. In a multipath fading environment, synchronous transmission gives about 3dB better performance than asynchronous transmission independent of the number of users. Also, we can observe the effect of multipaths on the performance by comparing the curve denoted by (1/8, 1/8) chip with (1/8, 10)chip. The simulation result confirms the effectiveness and advantages of the proposed method in a multipath environment.

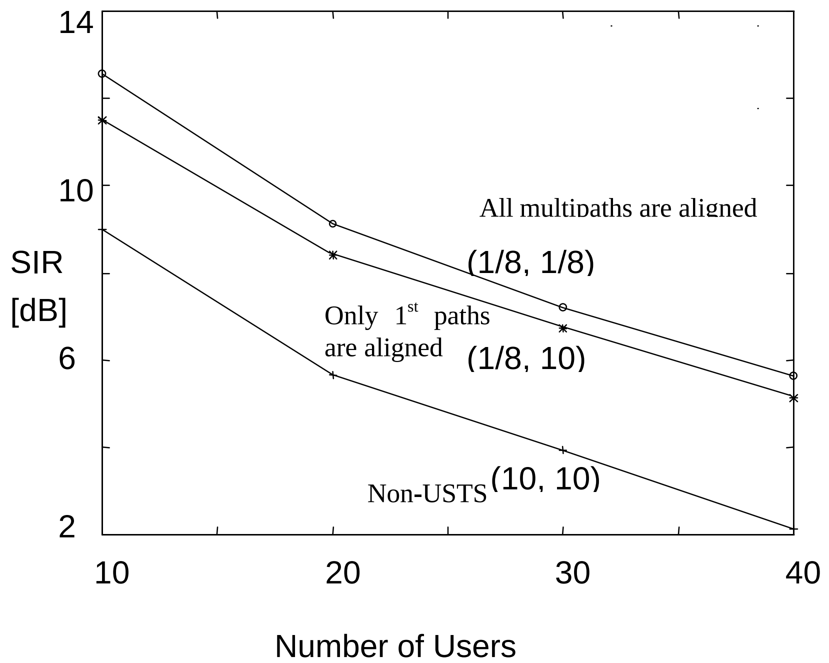

Fig. 3.1 SIR comparison

3.3 The effect of time misalignment (the effect of timing control resolution)

To consider the effect of time misalignment on performance in a synchronous transmission, the SIR according to fineness of synchronization is shown in Fig. 3.2. In this figure time misalignment of the first significant path is assumed to be within the value of abscissa and multipaths within the range the range of 10 chips. If it is possible to carry out uplink synchronization within the range of 1/2 chip, the effect of orthogonality on the performance can be acheived. As expected, however, the time misalignment larger than 1 chip duration causes severe performance degradation.

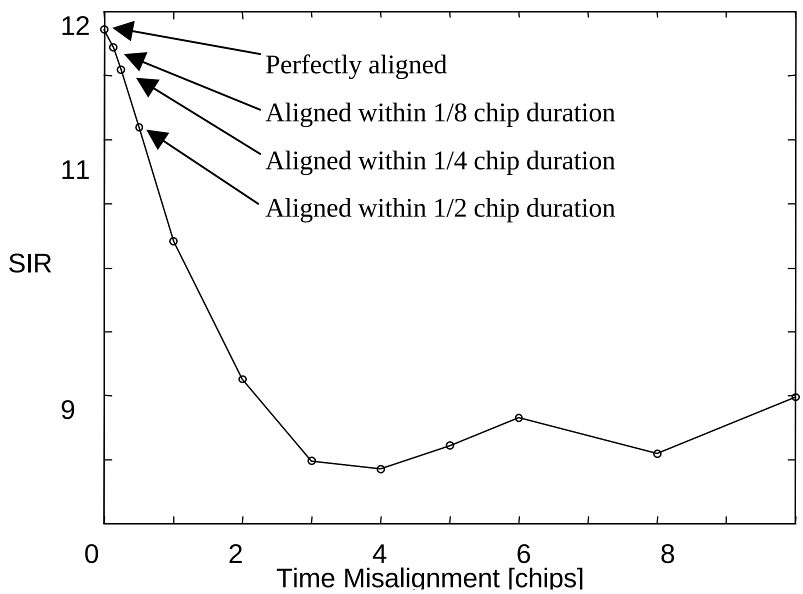

Fig. 3.2 The effect of time misalignment

3.4 The Effect of TAB error

Fig. 3.3 shows that the effect of decision error in Time Alignment Bit(TAB) on the performance of USTS. The error rate is assumed at 10% and 5% for showing the effect of error in TAB explicitly. The other conditions are the same as in Section 3.1 except the velocity of MS is assumed at 60km/h. The 5% and 10% error in TAB result in about 0.15dB and 0.4dB loss in Signal to Interference Ratio(SIR), respectively. Even if 10% error in TAB is assumed, the USTS shows about 2dB better performance than asynchronous transmission case.

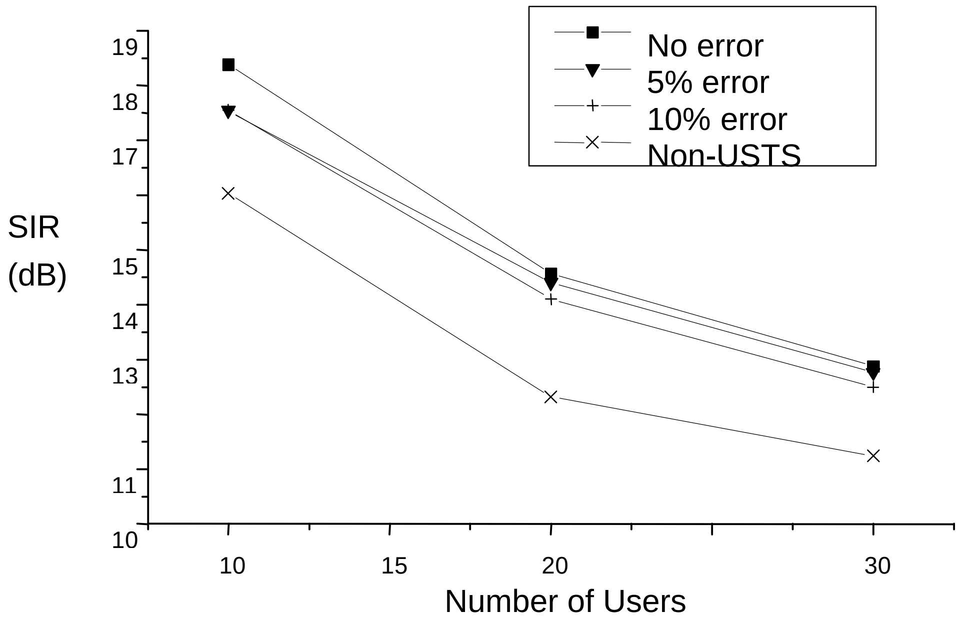

Fig. 3.3 The effect of TAB Error

3.5 Effects of the variation of the channel environment and timing control rate

The performance of the synchronous transmission was evaluated in comparison with the asynchronous transmission in the previous section. These results showed that the synchronous transmission gives about 3dB better performance than the asynchronous transmission when the difference of the arrival time among channels is kept less than 1/4 chip. However, channel conditions are changed in the mobile environment as each user moves and even the paths disappear due to the shadowing effect. Therefore, the delay of the channel signals from each MS to a CS is not maintained constantly, so the timing control process should overcome this kind of variation continuously to achieve synchronization between the first significant paths. The variation of the delay due to the variation of the channel environment was not considered in the previous paper. In this session, this kind of variation is considered by changing the delay parameter of each paths of received signal including the first significant path in a random manner. In addition, the effect of timing control rate is evaluated.

The vehicular B of ITU-R TG 8/1 channel model is adopted in our simulation. This channel model consists of 6 paths whose relative delays are 0, 310, 710, 1090, 1730 and 2510nsec and corresponding average power of 0, -1.0, -9.0, -10.0, -15.0 and –20.0 dB, respectively. The carrier frequency and vehicle velocity are assumed to be 1.9GHz and 20 km/h. In the synchronous transmission, 128-ary Walsh orthogonal code is used for identifying each MS and maximal length PN code of length 2^{15} is used for spreading. In the asynchronous transmission, each MS is identified with PN code phase offset.
Fig. 3.4 shows the amount of multiple access interference (MAI) on the dB scale according to the number of users, when the timing control ratio parameter N is 1,2,3,4,8 and 12. The parameter *N* represents the ratio of the timing control rate to the average channel variation rate. If the average channel variation interval is 100 ms and *N* is 4, the timing control process is carried out every 25ms. The step size of timing control is 1/4 chip and the maximum increment of delay variables is one chip. Synchronous transmission gives about 3 dB better performance than the asynchronous one irrespective

of the number of users when N exceeds 3. However, when N is 1 or 2, the performance improvement of the synchronous transmission is less than 1 dB and its effect is negligible. In addition, if the ratio of the timing control rate to the channel variation rate is above 3, the performance improvement is not notable in spite of increasing the value of N.

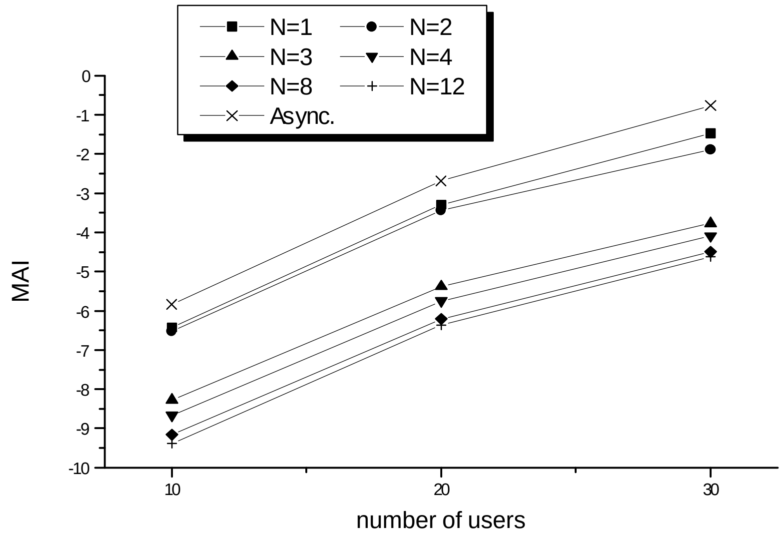

Fig. 3.4 The effect of timing control rate

References

[1] R1-00-0763, “Performance and feasibility of USTS”, SK Telecom
[2] SMG UMTS 56/98, “Reverse link synchronous transmission scheme”, TTA
[3] SMG UMTS-L1 226/98, “Reverse link synchronous transmission scheme”, TTA