3GPP TSG RAN WG1 #44-bis **R1-060867**
Athens, Greece, 27 - 31 March, 2006

Source:	**Texas Instruments**
Title:	**A new preamble shape for the Random Access preamble in E-UTRA**
Agenda Item:	**10.2.3**
Document for:	**Discussion**

1. Introduction

It is assumed that in E-UTRA, a UE uses a contention-based channel, the random access channel, to initiate a (new) resource allocation request. A random access attempt contains a preamble which design is driven by the primary purpose of allowing Node B to detect the random access attempt with targeted detection and false alarm probabilities, and minimize collisions impact on the contention-based channel. Optimization of random access preamble bandwidth/duration with respect to that aspect has already been addressed in [1]. In addition, Node B uses the random access preamble to perform UL synchronization of an out-of-sync UE. Finally, the random access preamble can be used by the Node B to derive the best UL resource allocation for the upcoming random access message or further L2/L3 data. The present contribution addresses this issue by proposing an alternate shape for the random access preamble.

2. Random Access usage for scheduling requests

RAN2 has agreed that the random access usage in E-UTRA is restricted to UE requesting (new) resources on SCH [2], [3]. A scheduling request may result from different UE situations: initial network access (DETACHED → ACTIVE state transition), new data to transmit in ACTIVE state, handover procedure, etc. However, it is assumed that for all these different cases, the information required and being conveyed by the scheduling request fits in a small payload referred to as random access message. Two options exist for transmitting this message:

1. The message is sent along with the preamble in the random access burst. In this case, the Node B demodulates/decodes the scheduling request and sends back to the UE the associated allocated resource on UL SCH, along with timing advance information and C-RNTI [2], if necessary.
2. The message is sent only after the Node B acknowledged back the random access preamble. In this case, only preamble transmission uses a contention-based channel, and the Node B sends back to the UE the associated allocated resource on UL SCH for the message, along with timing advance information and C-RNTI [2], if necessary.

In both cases, the Node B must allocate some UL resource to the UE based on known needs. In the following, UEs are assumed to be scheduled over localized frequency resource blocks, taking advantage of multi-user diversity. In absence of any knowledge of the UL frequency response over the system bandwidth, the Node B can only allocate UL resource blindly to the UE based only on the amount of UL resource that is requested and is available.

It was shown in [1] that a narrow band preamble of 2.5MHz provides optimum detection performance over the SNR range required for detection probability and false alarm targets of [0.9 – 0.999] and 10^{-3} respectively. Such narrow band also brings the advantage of leaving room in the spectrum for other preambles or scheduled data (TDM or TDM/FDM option). Unfortunately, it allows the Node B to estimate the UL channel quality for that UE within the preamble bandwidth only, so the Node B cannot perform UL resource allocation beyond the preamble bandwidth. Optimization of the UL resource allocation with respect to the channel frequency response calls for means of estimating the latter beyond the narrow preamble bandwidth.

We propose to address this issue by adding a wideband pilot that can be either attached or embedded to/in the preamble, and that the Node B will use for channel estimation upon preamble detection.

3. Random Access preamble with *attached* wideband pilot (option 1)

The 'T'-shape preamble shown in Figure 1 includes a wideband pilot attached at the preamble end. The pilot block should be kept short, typically of the same duration as the short block (SB) in the sub-frame format specified in [4].

Both pilot and preamble use sequences chosen randomly by the UE, but linked so that the Node B can derive the wideband pilot code from the preamble signature.

The preamble uses CAZAC sequences which discrete autocorrelations are zero for all nonzero lags [5]. Let's have a look at the orthogonal sequence space with an example. It was shown in [1] with a simple link budget analysis that a preamble duration of 1165 µs is needed to achieve a detection probability of 0.999 with 10^{-3} false alarm over a 5km cell. With such cell size, a maximum round-trip delay of 33.33 µs is expected, thus allowing for 35 cyclic shifted orthogonal versions of the sequence. The wideband pilot cannot use any cyclic shift of a given CAZAC sequence, given its duration is the same as the maximum round-trip delay. This calls for sequence sets with good auto- and cross-correlation properties such as ZCZ-GCL

[6] for the wideband pilot. However, this will reduce the sequence space for the wideband pilot compared to that of the preamble, resulting in a higher collision probability, given the preamble can also benefit from randomly choosing a frequency chunk in the access slot. On the other hand, the wideband pilot is expected to benefit from the coarse time estimation of the preamble. For example, for 2.5 and 1.25 MHz preambles, UEs with the same wideband pilot sequence will not collide if they are spaced apart by more than 60 and 120 meters, respectively, in the direction of the Node B. Moreover, they will also be orthogonal if they use CAZAC sequences.

Figure 1 shows examples of T-shape preambles for both the TDM/FDM and TDM-only multiplexing option. Note in the former case the wideband pilot is limited to the RACH access slot allocated bandwidth so that the concept best applies to the TDM-only option. This option adds a minimum overhead on the RACH burst length, given those already envisioned for coverage purpose (1-2ms, [1]), not accounting for the message when attached. Finally, with this option, pilot to other UE's preambles interference (and vice versa) is limited to the overlapping region due to non-aligned UEs (Figure 1).

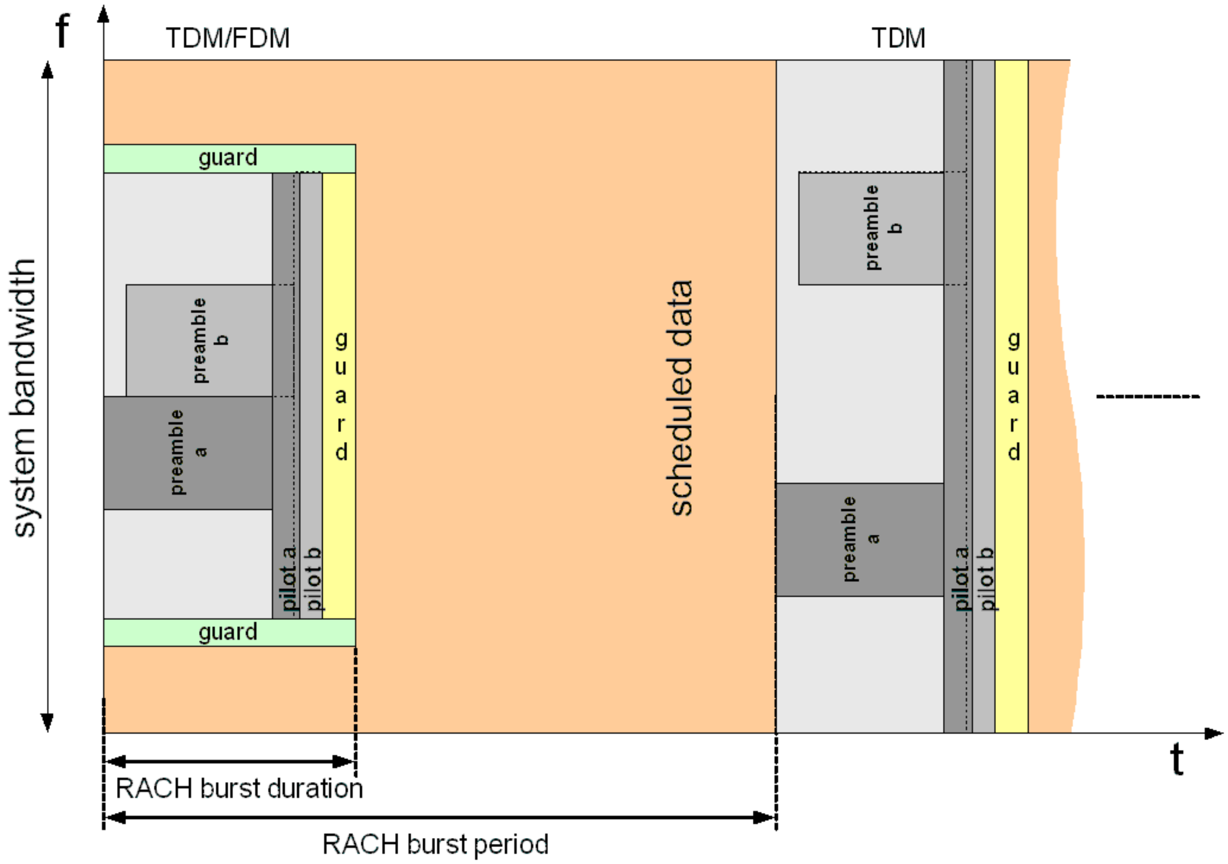

Figure 1: T-shape RACH preamble in FDM/TDM and TDM multiplexing options

4. Random access preamble with *embedded* wideband pilot (option 2)

The '+'-shape preamble shown in Figure 2 includes a wideband pilot merged with the preamble. The wideband pilot crosses the preamble at a time position depending on the frequency resource block used by the preamble, so as to allow time multiplexing pilots of different frequency multiplexed preambles, therefore offering the same collision avoidance performance. The pilot block should be kept short, typically of the same duration as the short block (SB) in the sub-frame format specified in [4].

The signature sequence of both the preamble and the pilot are such that they "coincide" in the crossing region: down-sampling the wideband pilot to the preamble sampling rate yields the preamble signature in this time interval, resulting in the wideband pilot bandwidth being an integer multiple of the preamble bandwidth.

It is shown in the Appendix how the "crossing region" requirement restricts the sequence space and the bandwidth ratio between wideband pilot and preamble when CAZAC sequences are chosen for both the preamble and wideband pilot [5]. Moreover, at cell edge, a UE may need to send the random access burst at maximum power, i.e. the same power for both preamble and pilot. As a result, the preamble samples picked from the wideband pilot will experience a power decrease compared to the non-pilot preamble samples, thus breaking the “constant amplitude” and therefore autocorrelation property of CAZAC sequences. As a result, more study needs to be done to check which of CAZAC sequences or other PN sequences are the most appropriate for this scheme.

Other options could be envisioned for the crossing region such as gating the preamble to let the wideband pilot alone, which would bring the benefit of letting preamble and pilot parameters being chosen independently.

Similar to Section 3, Figure 2 shows examples of preambles/pilots for both the TDM/FDM and TDM-only multiplexing option. The same comment applies, i.e. concept best applies to the TDM-only option. Note that this option yields no overhead on the random access burst length, as the wideband pilot duration is not added on top of the preamble duration.

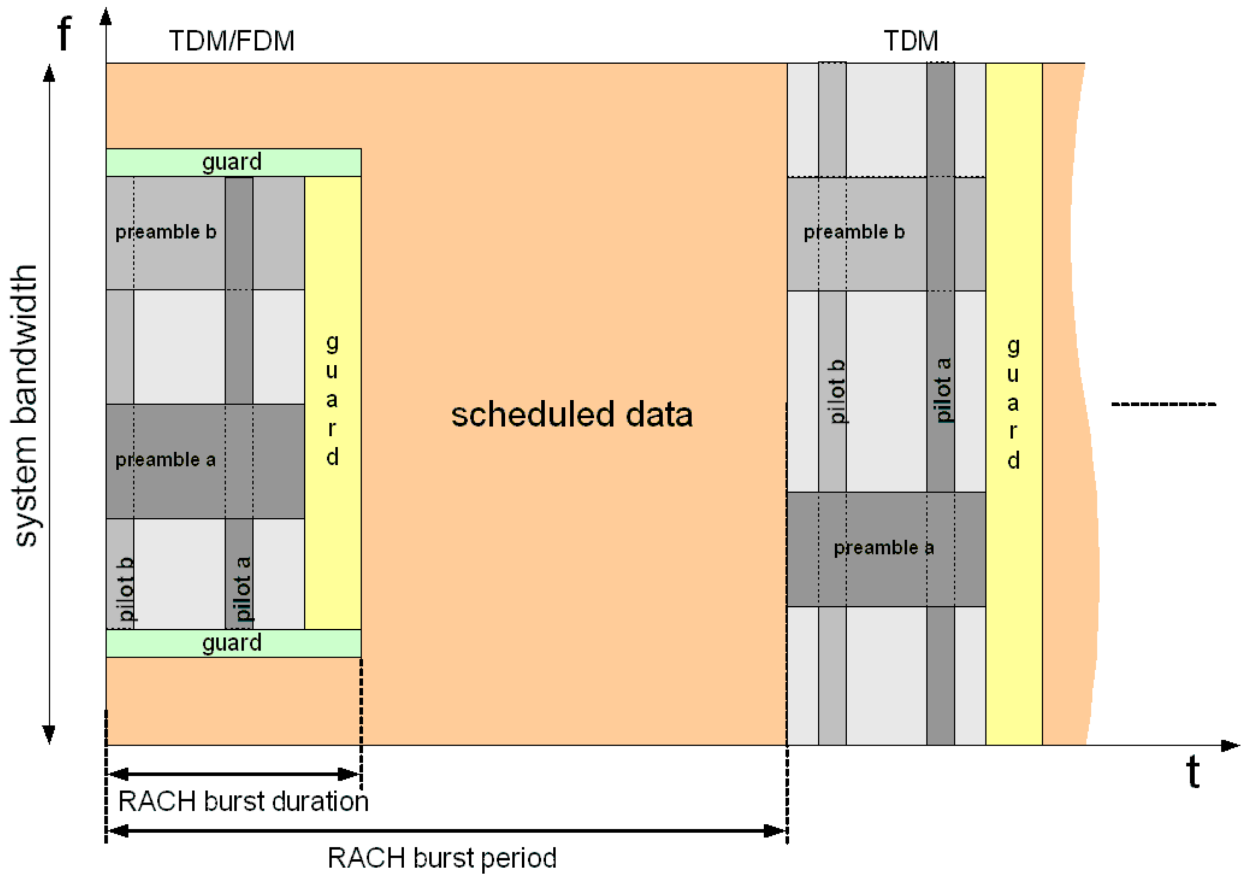

Figure 2: Random access preamble with embedded wideband pilot in FDM/TDM and TDM multiplexing options

5. Comparison of attached versus embedded pilot

Table 1 compares attached and embedded options with respect to different performance criteria.

Table 1: Comparison of attached versus embedded wideband pilot

Wideband pilot is:	**Attached**	**Embedded**
Preambles orthogonality and autocorrelation property	Good (CAZAC)	Medium
Wideband pilots collision avoidance	Low, not as good as preambles collision avoidance	As good as preambles collision avoidance
Overhead	Low	None
Wideband Pilot interference on other preambles	Low	Medium

6. Other benefits of the wideband pilot

The additional wideband pilot is motivated in Section 3 by the need for providing the Node B with some means for estimating the UL channel frequency response over the system bandwidth, thus enabling an appropriate UL resource allocation. In this section, we address how the wideband pilot can also improve the detection performance as well as the UE's timing estimation accuracy.

6.1. Detection performance

As illustrated in Figure 3, the wideband pilot can be seen as an additional signal that can be further used as a 2nd detection stage, to verify the random access reception upon preamble detection. As such it allows for a 2-stage detection process thus potentially improving the overall detection performance or reducing the preamble length for the same overall p_d and p_{fa} performance [7]. Quantitative assessment of the practical benefit if FFS.

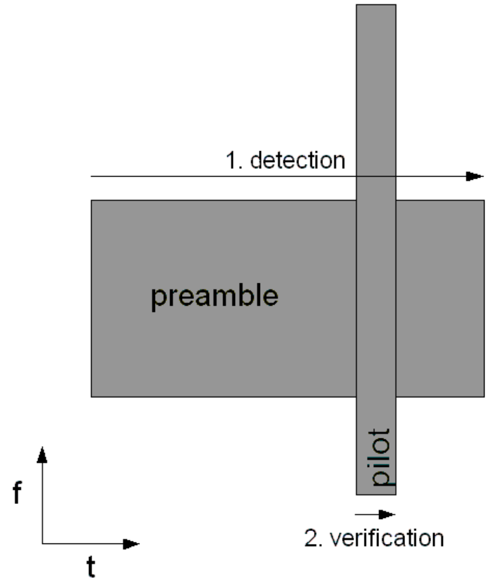

Figure 3: Random access preamble with wideband pilot used as a verification stage of the detection

6.2. Fine timing acquisition

The time synchronization precision after preamble detection is in the order of the inverse of the preamble bandwidth. As a result, exploiting the wideband pilot requires finer time granularity which is achieved by running wideband sample phase bins around the initial synchronization estimate on the wideband pilot. This also allows the Node B to send back to the UE a finer Timing Adjustment (TA) information.

The time synchronization quantitative improvement over the wideband pilot if FFS.

7. Conclusion

Given that random access usage in E-UTRA most of the time involves some UL scheduling request by the UE, we proposed in this contribution to add to the random access preamble a wideband pilot. This wideband pilot provides, with no or little overhead, support to the Node B for UL resource allocation to the UE for either the random access message or further L2/L3 data. Two implementation options are proposed: attached or embedded wideband pilot. In addition, this new scheme provides more potential benefits such as improved detection performance and finer time acquisition.

References

[1] R1-060376, "RACH Preamble Design", Texas Instruments

[2] 3GPP TR 25.813 V0.6.0, "Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Radio interface protocol aspects (Release 7)"

[3] R1-060061, R2-060144, "LTE L1 related questions to RAN1"

[4] 3GPP, TR-25.814, "Physical layers aspects of evolved UTRA (E-UTRA)"

[5] D.C. Chu, "Polyphase codes with good periodic correlation properties", IEEE Transactions on Information Theory, July 1972

[6] R1-060328, "RACH design for E-UTRA", Huawei

[7] Stephen S. Rappaport, Donald M. Grieco, "Spread Spectrum Signal Acquisition: Methods and Technology", June 1984, Vol 22, N°6, IEEE Communications Magazine

Annex 1 CAZAC sequences for random access preamble with embedded wideband pilot

CAZAC Zadoff-Chu sequences of length N whose discrete autocorrelations are zero for all nonzero lags are defined as [5]:

(1)
$$a_k = \exp\, j\frac{M\pi k^2}{N},\ N\ even$$
$$a_k = \exp\, j\frac{M\pi k(k+1)}{N},\ N\ odd$$

where M and N are relatively prime.

The signature sequence of both the preamble and the pilot are such that they "coincide" in the crossing region: down-sampling the wideband pilot to the preamble sampling rate yields the preamble signature in this time interval. As a result, the wideband pilot CAZAC sequence must be chosen so that the sequence resulting from picking 1 element every n is still a CAZAC sequence, which restricts the possible pilot sequences to:

(2)
$$a_k = \exp\, j\frac{M\pi (nk)^2}{N} = \exp\, j\frac{Mn^2\pi k^2}{N} = \exp\, j\frac{Mn\pi k^2}{N/n} \quad ; \quad k = 1,2,\cdots\frac{N}{n}$$

with the further restrictions on N, M and n:

- N is even
- n is odd
- Mn^2 and N are relatively prime

The condition on n is the most restrictive as it removes some flexibility on the wideband pilot over preamble bandwidth ratio.