CDMA/OFDM signals for various values of $M$ with QPSK transmission and $N=128$. In this Figure, the analytic results of the original OFDM signals with the SL approach are also given for using one, two and four statistically independent sequences corresponding to $S=1$, $2$, and $4$, respectively. The 0.1% PAR of the transformed CDMA/OFDM signals is reduced by 2-3 dB compared to that of the original CDMA/OFDM signals for the multi-user case with half user capacity. As described in the previous Section, further PAR reduction can be obtained by modifying the SLM approach. The 0.1% PAR of the OFDM-CDMA signals combined with the modified SLM approach using four statistically independent sequences of $S=4$ is reduced by up to 1 dB compared to that of the OFDM-CDMA signals with the original SLM approach employing two sequences of $S=2$, maintaining approximately same transmitter complexity. Unfortunately, one additional side information bit is required. However, under the condition of the same bits of the side information of log-$S=1$, the complexity of the modified SLM approach with $S=2$ is reduced by 25% compared with that of the original SLM approach with $S=2$, giving the nearly same PAR performance. The transmitter complexity is further reduced for larger value of $S$, and in the case of $S=4$ complexity reduction of 37.5% is obtained.

**Fig. 2** PAR performance of CDMA/OFDM system using symbol formatting for two different allocations of Walsh code sequences with QPSK transmission, $M=64$, $N=128$, and $P=10^{-5}$.

- - - - - original single user OFDM signal

- - - - selected Walsh code sequences

- - - - symbol formatting

- - - - Walsh code sequences in reverse order

- - - - - no symbol formatting

The PAR variation of the transmitted CDMA/OFDM signals versus the number of active users for both cases of symbol formatting and no symbol formatting with QPSK transmission, $M=64$, $N=128$, and $P=10^{-5}$. In this example, as described earlier, two different allocations of Walsh spreading codes are considered. As investigated in [6], Walsh spreading codes tend to have very large PAR for relatively few active users. For both allocation strategies, however, the PAR level of CDMA/OFDM signals using the symbol formatting is less than that of the original OFDM signals for relatively few active users. Using the Golay complementary codes for orthogonal spreading code instead of Walsh spreading codes is the alternative. As expected, when the system is fully loaded, the PAR is more or less independent of the Walsh code allocation patterns. Therefore, it is very interesting to consider the proposed simple approach in CDMA/OFDM based transmission systems because of no implementation burden and no loss in data rate, maintaining the same detection performance.

**References**


**Trial results from adaptive hand-over boundary modification in GERAN**

V. Wille, S. Pedraza, M. Toril, R. Ferrer and J.J. Escobar

Modification of hand-over boundaries allows restricting of the effective cell service area. This method has been used in GSM/EDGE radio access network (GERAN) to deal with traffic congestion that is caused by operator tariffs. Results from the application of this method in an actual network show that significant performance benefits can be obtained.

**Introduction**

The tariff policy of a cellular network operator has a paramount impact on the tele-traffic load in the network. Offering free off-peak (i.e. evening) calls will inevitably lead to an increase in the level of evening traffic as free mobile phone calls replace chargeable fixed-line calls. Owing to free evening airtime, the traffic tends to be generated in residential areas where day-time (i.e. peak) traffic is comparatively low. As a consequence, network capacity would have to be added in these areas to cater for calls that provide no extra call revenue. To maximise revenue, operators aim to handle this additional off-peak traffic demand with the existing network infrastructure. This goal can be achieved if spare capacity, which may be available in some cells, can be utilised to carry traffic from the congested cells, so additional resources do not have to be deployed to cope with new capacity demands. It is important to bear in mind that, under normal conditions, traffic balancing between cells is not possible, since calls are handled by the cell that offers the strongest/best signal level (i.e. minimum pathloss). This principle is generally applied, since interference can be minimised when mobiles are connected to the best-serving cell, where power-control can be used effectively to reduce the transmit power of both the base station and the mobile terminal.

**Fig. 1** HO boundary displacement between cell A and B by means of margin adaptation.

- - - - - signal level distribution with distance from BTS

- - - - - connection signal level for HO PBGT margin = 6 dB

- - - - - connection signal level for HO PBGT margin = 12 dB
Traffic sharing methods: Two methods for carrying traffic on a suboptimal serving cell in GERAN are described in the literature: directed-retry and modification of hand-over (HO) boundaries. Directed-retry [1] is applied during the call setup phase, directing calls from a congested best-serving cell to a surrounding cell that also provides coverage in the area where the call attempt is being made. However, very shortly after call establishment a HO from the non-optimal cell to the best-serving cell will be attempted. Therefore, this feature, while reducing blocking of call attempts, only provides little permanent capacity increase. Modification of the HO boundaries [2, 3] allows reusing of the effective service area to match the spatial traffic distribution in the network. It is thus possible to reduce the 'size' of a congested cell whilst enlarging the 'size' of an adjacent cell with spare capacity. Hence, the traffic handling capability of the network is tailored to the traffic demand, i.e. the effective network capacity is increased compared to the use of normal HO boundaries. It is worth noting that this method does not reduce coverage levels in the network as HO parameters are modified instead of cell output powers.

Adaptive HO boundary method in GERAN: Cell resizing is achieved by modifying the so-called power budget (PBGT) handover margin. This parameter determines how much stronger the signal level from a neighbouring cell has to be before attempting a best-server (i.e. PBGT) HO. In common propagation environments, this PBGT margin is set to a fixed value that counteracts ping-pong handover due to shadow fading. The adaptation principle is shown in Fig. 1, where the handover of a mobile station moving from cell A to cell B is analysed. Cell signal level distributions (dotted line), together with the signal level experienced by the user (dashed and solid bold line), have been depicted over distance. To enlarge cell A with respect to cell B, the HO margin A → B is raised from 6 to 12 dB, i.e. signal level from cell B has to be 12 dB stronger than that of cell A for a call to be handed over. From Fig. 1, it can clearly be observed that the service area of cell A has been enlarged in the direction of cell B. It is worth noting that Fig. 1 shows the HO boundary principle only for a pair of cells, although this principle can be simultaneously applied to all neighbouring cells that mobiles can be handed to.

The adaptation of the HO boundaries aims at balancing traffic between neighbouring cells. Congestion time is used as an estimator for call blocking probability in a cell. Changes to the PBGT margin are proportional to the difference in congestion time experienced by each pair of cells, resulting in permanent modification of cell service area. Likewise, the PBGT margins from A → B may be different than those from A → C.

Trial setup: The above-described methodology has been applied to a live network twice daily to deal with the peak-time and off-peak-time traffic behaviour resulting from tariff policy. The trial area consisted of 95 cells providing seamless coverage. The PBGT margins on the adjacencies of all these cells were amended in both time periods based on the respective congestion time observed on the previous day. The analysis of this data proved suitable, since the call volume in a cell remained virtually unchanged from Monday to Friday within the peak and off-peak period.

Trial results: The results displayed here cover a time interval of two consecutive weeks. The method was enabled (i.e. ON) during the first week, whereas it was disabled (i.e. OFF) in the following week. To determine the impact of the method on the network, comparison of the traffic carried in the network during these two weeks must be drawn first. Fig. 2 shows the sum of busy hour (BH) traffic carried by the trial cells for four consecutive days with and without the use of the method. It is observed that the traffic level during both weeks was quite similar. The overall daily BH traffic averaged over the corresponding four days was 1012.1 Erl when the method was ON, while the respective traffic during the OFF period was 979.9 Erl. This means that when the method was active the traffic level was on average 3.3% higher than during the inactive period.

Fig. 3 shows the daily call blocking rate averaged over the trial area for both periods. It can be noticed that the average blocked call rate was 1.7% when the method was ON, whilst this rate raised to 3.7% (i.e. 54% increase) when the method was OFF. This blocking rate increase during OFF period was noticed despite the fact that the carried traffic reduced by 3%. These results show conclusively that the method enables the network to carry more traffic and reduce call blocking, and thus increase the effective network capacity.

It is worth noting that the dropped call rate also benefited from the method, caused possibly by a higher handover success rate due to congestion relief in the network. When the method was in use, the dropped call rate averaged about 1.6%, while the dropped call rate increased to 2.3% (i.e. 31% increase) when it was OFF. This improvement was achieved at the expense of a slight call quality impairment, expected due to the fact that some calls were not carried by the best-serving cell but the next best cell offering spare capacity instead.

Conclusions: The principle of HO boundary modification has been applied in a real network in order to deal with congestion problems caused by operator tariff policy. Modifying the HO margins twice a day on an adjacency-by-adjacency basis, it was shown that more traffic could be carried in the network while also reducing the blocking of call setup attempts. The call quality deteriorated slightly, since some calls were not carried by the best-server cell but the second best instead. However, this deterioration is outweighed by the benefit that more traffic can be handled by the network without the need for any hardware upgrades, thus providing a cost-effective method to increase network capacity.

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Characteristics of small-signal capacitances of silicon-on-sapphire MOSFETs

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The measured inter-electrode capacitance of silicon-on-sapphire (SOS) MOSFETs are presented and compared with simulation results. It is shown that the variations of capacitance with DC bias differ from those of bulk MOSFETs due to change in body potential variations of the SOS device resulting from electron-hole pair generation through impact ionisation.

Introduction: The main difference between silicon-on-insulator (SOI) MOSFETs (of which the silicon-on-sapphire (SOS) device in a thin film) and bulk MOSFETs is that the former has an isolated body. While such a structure has many inherent advantages such as reduced junction capacitance and immunity to CMOS latch-up, it suffers from the effects of a floating body which can significantly affect the device electrical characteristics under high drain fields [1]. The effect of impact ionisation on the DC drain current is well documented but the small-signal parameters of the device. With the device size shrinking, the effects of impact ionisation on the DC and AC characteristics are more pronounced. In this Letter we present experimental and simulation results of small-signal gate-to-drain (Cgd) and gate-to-source (Cgs) of an SOS device and highlight the effect of impact ionisation.

Device and method: Partially depleted SOS n-channel transistors with 0.5 μm drawn length, 10 nm gate oxide fabricated on 100 nm thin film silicon were used to investigate the effects of impact ionisation. Cgs and Cgd were measured against drain and gate bias using an HP 4284A LCR meter. DC characteristics were also measured using a semiconductor parameter analyser. The effect of impact ionisation on device characteristics was studied theoretically by numerical simulation of the test device with and without impact ionisation physics using the 2-D device simulator SILVACO [2].

Results: For a bulk device in inversion, \( C_{gs} = C_{gd} = 0.5C_{gsox} \) at \( V_{ds} = 0 \) V, where \( C_{gsox} \) is the total gate capacitance (= \( C_{gso} W/L \)). As \( V_{ds} \) increases, \( C_{gs} \) rises towards 2/3 \( C_{gsox} \) and \( C_{gd} \) decreases towards zero [3]. Fig. 1 shows the measured \( C_{gs} \) and \( C_{gd} \) against \( V_{ds} \) for the 0.5 μm-length SOS n-MOSFET at \( V_{ds} = 1 \) V (\( V_{gs} = 0.7 \) V). \( C_{gs} \) rises with increasing \( V_{ds} \) but reaches a plateau at \( V_{ds} = 0.25 \) V and then rises again after 1.2 V. \( C_{gd} \) decreases with increasing \( V_{ds} \) initially but shows a small peak at \( V_{ds} = 1.6 \) V before decreasing again. The plot of \( L - V_{ds} \) at \( V_{gs} = 1 \) V for the device is also shown in Fig. 1. It can be seen that there are three regions of \( C_{gs} \) closely aligned with the rapid rise in drain current at the onset of impact ionisation [4] at \( V_{ds} = 1.2 \) V. Impact ionisation induces a forward bias on the body-to-source junction and hence lowering of threshold voltage and an increase in inversion carrier concentration at the source end of the channel. Theory of MOSFET gate capacitances shows that this leads to increase in \( C_{gs} \) and a concomitant decrease in \( C_{gd} \) [3]. We attribute the observed increase in \( C_{gs} \) to this effect. The peaking at \( V_{ds} = 1.6 \) V and delayed decrease in \( C_{gd} \) require explanation. To investigate this, a two-dimensional device simulation of the measurement was carried out. For simplicity, we used a uniformly doped substrate and step junctions for the source and drain. The simulation capacitances with and without impact ionisation physics (with SILVACO default para-


Fig. 1 Measured \( C_{gs} \), \( C_{gd} \) and drain current against \( V_{ds} \) of \( W/L = 20/0.5 \mu m \) SOS n-MOSFET at \( V_{gs} = 1 \) V

Fig. 2 Simulated per unit width \( C_{gs} \), \( C_{gd} \) and drain current against \( V_{ds} \) of \( L = 0.5 \mu m \) SOS n-MOSFET at \( V_{gs} = 1 \) V

- with impact ionisation
- without impact ionisation

Fig. 3 Simulated change in back surface potential of SOS n-MOSFET at \( V_{gs} = 1 \) V and \( V_{ds} = 1.4 \) V in response to 10 mV change in \( V_{gs} \)
Inset: Mid-channel electron concentration profile
- with impact ionisation
- without impact ionisation

To understand the behaviour of \( C_{gs} \) we simulated and plotted in Fig. 3 the change in back surface potential of the SOS transistor with...