TECHNICAL PAPER

Title: **A Novel Code Planning Approach for a WCDMA Network**

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Abstract—*This paper explains the background of WCDMA scrambling code planning and the theory behind a planning technique where a site's primary DL scrambling codes belong to the same code group. The paper then goes on to describe the tests performed on a test platform and on a network, and the results achieved. Finally, the paper summarizes the code planning technique and the benefits over other code allocation schemes.*

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INTRODUCTION

Using trial networks, many tests have been performed to verify wideband code division multiple access (WCDMA) network performance—from cell ranges to handover success rates. One such test involves analyzing the best method of downlink (DL) scrambling code allocation. This paper presents a novel approach to code planning that provides a marked improvement in coverage probability compared to other code planning schemes.

Unlike previous frequency division multiple access (FDMA) mobile networks, WCDMA networks do not require frequency planning, since a common carrier can be used across all cells. Instead, WCDMA relies on the concept of scrambling codes to differentiate among cells in the DL.

Code planning within a WCDMA network is generally done by a radio network planning team. Many commercial or in-house planning tools now have the capability to automatically assess code reuse within a network and allocate the DL scrambling codes accordingly.

Rather than using a code allocation strategy that maximizes code reuse, one novel method of code planning employs an approach wherein a site's primary DL scrambling codes belong to the same code group. This method has a number of beneficial features, including simple code allocation strategy, high code reuse, field-engineer-friendly allocation strategy, and improved call/handover success rate.

BACKGROUND INFORMATION

The synchronization channel (SCH) is a DL channel used by the user equipment (UE) for the initial cell search. The SCH consists of two subchannels: the primary SCH (P-SCH) and the secondary SCH (S-SCH).

The 10 ms radio frames of the P-SCHs and S-SCHs are divided into 15 time slots, each with a length of 2,560 chips. Each block within the P-SCH consists of a modulated code, called the primary synchronization code (PSC), with a length of 256 chips. The PSC is unique within the network (the same for all cells in the system). Only one modulated block is transmitted at the beginning of each slot.

The S-SCH is transmitted in parallel with the P-SCH. Like the P-SCH, it has a data rate of 15 kbps, and only one 256-chip block per slot is transmitted at the beginning of each slot.

A secondary synchronization code (SSC) modulates each S-SCH block. There are 16 SSCs. Each block of the S-SCH, transmitted at the beginning of each slot, can be modulated by a different SSC. The combination of SSCs that modulate the S-SCH symbols within a frame has a one-to-one mapping with the primary scrambling code group used in the cell. The S-SCH sequence is, therefore, determined by the primary scrambling code planning.

ABBREVIATIONS, ACRONYMS, AND TERMS

BCCH	broadcast control channel
BTS	base transceiver station
C/I	carrier-to-interference (ratio)
CPICH	common pilot channel
DL	downlink
E_c	signal energy within one chip duration of a pilot signal
E_c/I_o	ratio of the signal energy within one chip duration of the pilot signal to the power spectrum of the interface and noise
FDMA	frequency division multiple access
LOS	line of sight
NLOS	nonline of sight
PSC	primary synchronization code
P-SCH	primary synchronization channel
SCH	synchronization channel
SSC	secondary synchronization code
S-SCH	secondary synchronization channel
UE	user equipment
WCDMA	wideband code division multiple access

CODE PLANNING METHODOLOGY

As described above, the S-SCH sequence is dictated by the DL primary scrambling code planning. If a site's DL primary scrambling codes belong to the same code group, then the P-SCH and S-SCH sequences are the same for all cells of the site. If, on the other hand, the site's DL primary scrambling codes belong to different groups, then the cells' S-SCH sequences are different, and only the P-SCH sequences are the same.

If the same code group is used, then the S-SCH symbols from the different cells of the site can be superimposed (by synchronizing the time offset between cells) to create stronger P-SCH and S-SCH signals as measured by the UE.

A simple code planning methodology exploits the properties of the S-SCH mentioned above to make code management straightforward. A software tool (developed internally by Bechtel) loads the site database and assigns DL scrambling codes on a code-group basis. Each site is allocated a code group, and individual cells within the site are allocated codes from that group, starting with the first code of the group for the first cell of the site and so on.

A carrier-to-interference (C/I) ratio computation algorithm within the tool ensures that code group reuse distance (or DL scrambling code reuse distance) meets the necessary planning requirements.

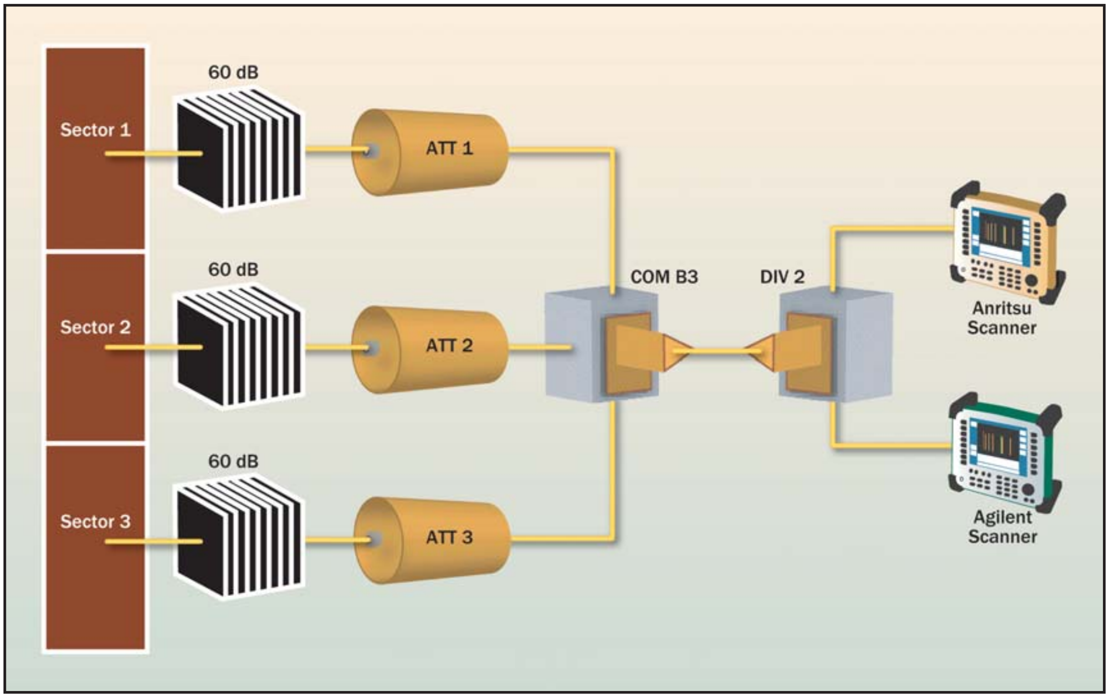


Figure 1. Laboratory Test Configuration

TESTS PERFORMED

To quantify the performance of this method of enhancing P-SCH and S-SCH signals, pilot channel power (E_c) and the ratio of average pilot channel power to total signal power (notationally represented as E_c/I_o) were measured and compared for both line-of-sight (LOS) and nonline-of-sight (NLOS) environments. The measurements were completed for both 0- and 256-chip frame timing offsets between the cells of the measured site. Laboratory measurements were also made and used as a reference. Finally, extended test runs were performed to assess the handover success rate using both 0- and 256-chip frame timing offset in the cells of the sites involved in the run.

Laboratory Tests

Figure 1 illustrates the configuration used for the laboratory tests.

Both Agilent and Anritsu WCDMA scanners were used and hardwired to the base transceiver station (BTS) antenna points via attenuators to balance the individual signal levels. Samples of SCH and common pilot channel (CPICH) signal levels were recorded for a period of time without varying the attenuation between the Node B antenna point and the scanner input. The configuration was unaltered for all test cases.

The test cases considered were:

- *All sectors with DL scrambling codes belonging to the same code group.* Both 0- and 256-chip (1 symbol) frame timing offsets were considered.
- *All sectors with DL scrambling codes belonging to different code groups.* Again, both 0- and 256-chip (1 symbol) cell frame timing offsets were considered.

Test for Same Code Group – Results for 256-Chip Frame Timing Offset

Table 1 summarizes the mean E_c and E_c/I_o levels for all three cells of the Node B under test. The DL scrambling codes belong to Code Group 1 and are Codes 1, 2, and 3 for the corresponding cells.

Test for Same Code Group – Results for 0-Chip Frame Timing Offset

Table 2 lists results for the same code group measurements, but with a frame timing offset between 0-chip cells.

Analysis of Same Code Group Test Results

Since DL scrambling codes from the same code group are being used, it would be expected that the E_C would be about three times higher on both the P-SCH and S-SCH than for the previous case, because the symbols are identical and the time is aligned. The mathematical differences between these two sets of results are given in **Table 3**.

Averaging the results shown in Table 3 (see last row) confirms that there is a gain of E_c and E_c/I_o of around 3 (4.8 dB) for the SCH subchannels when the frame timing offset is set to 0 chips and the same code group codes are used for all cells of the site.

Test for Different Code Groups – Results for 256-Chip Frame Timing Offset

To further substantiate the above findings, the same tests were performed for the code planning

Table 1. Same Code Group – 256-Chip Frame Timing Offset

SAME CODE GROUP, 256-CHIP OFFSET				
Cell 1 SC1	-10.38 dB	-51.54 dBm	-10.88 dB	-52.04 dBm
	PSCH E_c/I_o	PSCH E_c	SSCH E_c/I_o	SSCH E_c
Cell 2 SC2	-9.23 dB	-50.40 dBm	-10.27 dB	-51.44 dBm
	PSCH E_c/I_o	PSCH E_c	SSCH E_c/I_o	SSCH E_c
Cell 3 SC3	-10.49 dB	-51.65 dBm	-10.54 dB	-51.70 dBm
	PSCH E_c/I_o	PSCH E_c	SSCH E_c/I_o	SSCH E_c

Table 2. Same Code Group – 0-Chip Frame Timing Offset

SAME CODE GROUP, 0-CHIP OFFSET				
Cell 1 SC1	-5.67 dB	-46.49 dBm	-5.84 dB	-46.66 dBm
	PSCH E_c/I_o	PSCH E_c	SSCH E_c/I_o	SSCH E_c
Cell 2 SC2	-5.10 dB	-45.86 dBm	-5.33 dB	-46.09 dBm
	PSCH E_c/I_o	PSCH E_c	SSCH E_c/I_o	SSCH E_c
Cell 3 SC3	-5.10 dB	-45.86 dBm	-5.33 dB	-46.10 dBm
	PSCH E_c/I_o	PSCH E_c	SSCH E_c/I_o	SSCH E_c

Table 3. Same Code Group – Differences Between 0- and 256-Chip Frame Timing Offsets

SAME CODE GROUP, 0- AND 256-CHIP OFFSET DIFFERENCES				
Cell 1 SC1	4.71 dB	5.05 dB	5.04 dB	5.38 dB
	PSCH E_c/I_o	PSCH E_c	SSCH E_c/I_o	SSCH E_c
Cell 2 SC2	4.13 dB	4.54 dB	4.94 dB	5.34 dB
	PSCH E_c/I_o	PSCH E_c	SSCH E_c/I_o	SSCH E_c
Cell 3 SC3	5.40 dB	5.79 dB	5.20 dB	5.60 dB
	PSCH E_c/I_o	PSCH E_c	SSCH E_c/I_o	SSCH E_c
Averages	4.75 dB	5.13 dB	5.06 dB	5.44 dB

It is clear that a gain for both the P-SCH and S-SCH is achieved only by using the same code group allocations for each site and by having the SCH subchannels aligned.

method that does not prescribe using the same code group codes for each site. The DL scrambling codes used on the three sectors of the test site were 1, 17, and 34, which correspond to the different Code Groups 1, 2, and 3. **Table 4** summarizes the E_c and E_c/I_o levels for the three test cells of the Node B with relative frame timing offsets of 0, 256, and 512 chips, respectively.

In this case, the P-SCH transmission is the same for all cells of the Node B, but the S-SCH is different. Thus, no gain is expected on the S-SCH by aligning the P-SCH and S-SCH blocks (zero relative frame timing offset). This is verified by the measurement results of the next section.

Test for Different Code Groups – Results for 0-Chip Frame Timing Offset

Results for the same configuration as in the previous section, but with 0-chip frame timing offset, can be seen in **Table 5**.

Analysis of Different Code Groups Test Results

The mathematical differences for the cases where different code groups are used can be seen in **Table 6**.

Since, with different code groups, only the P-SCH is the same among cells, aligning cell SCH symbols is beneficial only for the P-SCH and not for the S-SCH. Thus, it is clear that a gain for both the P-SCH and S-SCH is achieved only by using the same code group allocations for each site and by having the SCH subchannels aligned.

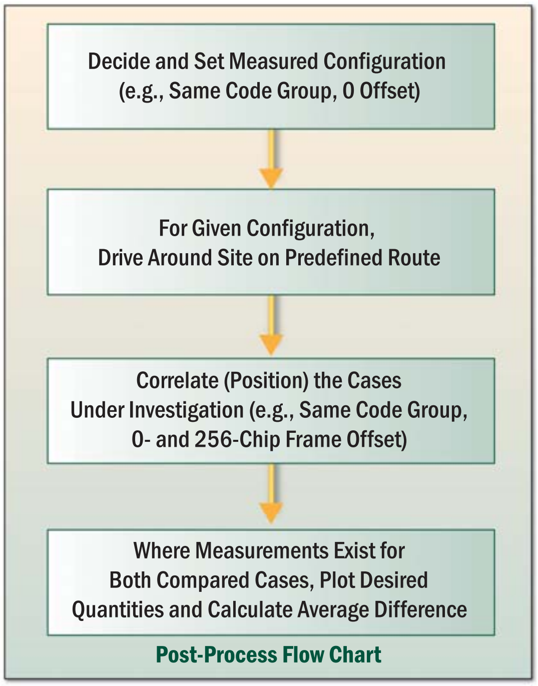


Figure 2. Measurement and Post-Processing Methodology

Table 4. Different Code Groups – 256-Chip Frame Timing Offset

DIFFERENT CODE GROUPS, 256-CHIP OFFSET				
Cell 1 SC1	-10.18 dB	-51.38 dBm	-11.17 dB	-52.37 dBm
	PSCH E_c/I_o	PSCH E_c	SSCH E_c/I_o	SSCH E_c
Cell 2 SC17	-9.65 dB	-50.85 dBm	-10.39 dB	-51.59 dBm
	PSCH E_c/I_o	PSCH E_c	SSCH E_c/I_o	SSCH E_c
Cell 3 SC34	-10.70 dB	-51.90 dBm	-10.61 dB	-51.80 dBm
	PSCH E_c/I_o	PSCH E_c	SSCH E_c/I_o	SSCH E_c

Table 5. Different Code Groups – 0-Chip Frame Timing Offset

DIFFERENT CODE GROUPS, 0-CHIP OFFSET				
Cell 1 SC1	-5.82 dB	-46.69 dBm	-11.45 dB	-52.32 dBm
	PSCH E_c/I_o	PSCH E_c	SSCH E_c/I_o	SSCH E_c
Cell 2 SC17	-5.54 dB	-46.34 dBm	-9.67 dB	-50.46 dBm
	PSCH E_c/I_o	PSCH E_c	SSCH E_c/I_o	SSCH E_c
Cell 3 SC34	-5.54 dB	-46.34 dBm	-10.74 dB	-51.54 dBm
	PSCH E_c/I_o	PSCH E_c	SSCH E_c/I_o	SSCH E_c

Table 6. Different Code Groups – Differences Between 0- and 256-Chip Frame Timing Offsets

DIFFERENT CODE GROUPS, 0- AND 256-CHIP OFFSET DIFFERENCES				
Cell 1 SC1	4.71 dB	5.05 dB	-0.27 dB	0.06 dB
	PSCH E_c/I_o	PSCH E_c	SSCH E_c/I_o	SSCH E_c
Cell 2 SC2	4.13 dB	4.54 dB	0.73 dB	1.13 dB
	PSCH E_c/I_o	PSCH E_c	SSCH E_c/I_o	SSCH E_c
Cell 3 SC3	5.16 dB	5.56 dB	-0.13 dB	0.27 dB
	PSCH E_c/I_o	PSCH E_c	SSCH E_c/I_o	SSCH E_c
Averages	4.54 dB	4.92 dB	0.11 dB	0.48 dB

A final laboratory test involved forcing the UE to perform a softer handover many times under each of the four sets of conditions outlined above. In all test cases, a 100 percent handover success rate was observed, leading to the conclusion that using the same code group and 0-chip frame timing offset between cells of the same site does not lead to synchronization problems during handover.

Field Tests

The field tests covered two main scenarios: the LOS and NLOS cases. The experimental procedure followed is illustrated in **Figure 2**.

The LOS case was expected to yield results that related closely to the theory, since a single dominant path with short delays between the antennas and the UE closely imitates synchronized wire connections. However, sectorization effectiveness was the dominant limiting factor, since high sector isolation (small overlap areas) gave few places where P-SCH and S-SCH gain was evident (for 0-chip frame timing offset).

To check the validity of the laboratory results, field measurements were filtered during post-processing to include data from overlap areas. For reasons of simplicity and realism, however, post-processing results were chosen from the total drive area around the site.

In the NLOS case, signals were highly scattered, averaging larger and more unpredictable overlapping coverage areas and leveling the results.

LOS Case

The site chosen for LOS measurements was a large office building with three antennas mounted on different sides. This site was ideal for general LOS measurements, since, at any given point in the drive route around the site, the UE antenna always had LOS with the corresponding sector antenna. However, sector overlapping was small and most probably came from reflections, since there was no area where the UE had LOS with two sectors. As a result, the P-SCH and S-SCH gain is small when 0-chip frame timing offset is used.

- Same Code Group – Comparison of 0- and 256-Chip Frame Timing Offsets

  For each cell of the chosen site, the difference between E_c/I_o measurements for 0- and 256-chip offsets was averaged to give an estimate of E_c/I_o gain/loss between the two cases.

  Table 7 summarizes the results for the case where all three cells of the site were allocated primary scrambling codes from the same code group. In this particular case, although there is very small sector overlap, an average E_c/I_o gain of 1 dB results when 0-chip frame timing offset is used.

  Results for sector 3 show no gain, since it is almost completely "isolated."

- Different Code Groups – Comparison of 0- and 256-Chip Frame Timing Offsets

  The same measurements as above were repeated with primary scrambling codes belonging to different code groups allocated to the three sectors, as shown in **Table 8**.

Table 7. Same Code Group – E_c/I_o Comparison of 0- and 256-Chip Frame Timing Offsets

TEST SITE 1				
	Cell 1	Cell 2	Cell 3	Average
PSCH E_c/I_o 0 vs. 1	2.01 dB	1.51 dB	-0.19 dB	1.11 dB
SSCH E_c/I_o 0 vs. 1	1.61 dB	1.55 dB	-0.40 dB	0.92 dB

Table 8. Different Code Groups – E_c/I_o Comparison of 0- and 256-Chip Frame Timing Offsets

TEST SITE 1				
	Cell 1	Cell 2	Cell 3	Average
PSCH E_c/I_o 0 vs. 1	1.82 dB	0.72 dB	0.88 dB	1.14 dB
SSCH E_c/I_o 0 vs. 1	0.79 dB	-0.10 dB	0.39 dB	0.36 dB

  The results follow the expected trend. A gain on the P-SCH is seen, as in the previous case, but the S-SCH gain is close to zero (theory). The error in absolute values is due to measurement tolerance and data variance.

NLOS Case

Another site was chosen for the NLOS tests—a rooftop site located on the ridge of a hill. Cells 1 and 3 overlooked the downward slope and had good overlap between them, whereas Cell 2 faced out over the plateau of the hill, resulting in poor overlap with the other two sectors. The results reflect these peculiarities, with Cells 1 and 3 having measurable gains, whereas Cell 2 has insignificant gain.

- Same Code Group – Comparison of 0- and 256-Chip Frame Timing Offsets

  As in the LOS case, the average difference between SCH E_c/I_o measurements for 0- and 256-chip frame timing offsets was calculated for each cell. **Table 9** provides the results for the case where all three cells of the site were allocated primary scrambling codes from the same code group.

  As expected, due to extensive scattering, the overlap areas are generally larger (because they not as confined as in the LOS case), resulting in higher gains. It is also evident that because Cell 2 has little overlap with the other cells, a smaller gain is obtained compared to the other cells.

In all test cases, a 100 percent handover success rate was observed, leading to the conclusion that using the same code group and 0-chip frame timing offset between cells of the same site does not lead to synchronization problems during handover.

- Different Code Groups – Comparison of 0- and 256-Chip Frame Timing Offsets

  With each cell allocated a primary scrambling code from a different code group, the same measurements were repeated. As for the LOS case, the expected gain on the P-SCH and no gain on the S-SCH are borne out by the test results, which are presented in **Table 10**.

With careful code planning, it is possible to maximize code reuse while taking advantage of similar S-SCH code blocks by adjusting frame timing to gain some P-SCH and S-SCH E_c/I_0 coverage (up to 2 dB in the field in some cases).

Soft/Softer Handoff Success Rate

A further field test involved extensive drive testing on a predefined route around a cluster of seven sites to test the soft/softer handoff success rate with the frame timing offset for all cells set to zero. Under normal conditions, the number of handoffs during a given run varies between 200 and 300, and the handoff success rate is 100 percent. **Table 11** tabulates the results for a typical run.

Table 9. Same Code Group – E_c/I_0 Comparison of 0- and 256-Chip Frame Timing Offsets

TEST SITE 2				
	Cell 1	Cell 2	Cell 3	Average
PSCH E_c/I_0 0 vs. 1	3.25 dB	0.85 dB	1.74 dB	1.95 dB
SSCH E_c/I_0 0 vs. 1	3.39 dB	0.84 dB	1.65 dB	1.96 dB

Table 10. Different Code Groups – E_c/I_0 Comparison of 0- and 256-Chip Frame Timing Offsets

TEST SITE 2				
	Cell 1	Cell 2	Cell 3	Average
PSCH E_c/I_0 0 vs. 1	2.53 dB	0.86 dB	1.55 dB	1.65 dB
SSCH E_c/I_0 0 vs. 1	0.68 dB	0.30 dB	0.39 dB	0.46 dB

Table 11. Field Handover Success Rate – 0-Chip Frame Timing Offset

MESSAGE	ACTIVE_SET_UPDATE	ACTIVE_SET_UPDATE_COMPLETE
RRCD	232	
RRCU		232
Total	232	232
Soft/Softer Handoff Success Rate		100%

UE Camp-On Time

As a final verification, the time from UE power-up until cell acquisition (reception of the first broadcast control channel [BCCH] message) was measured for all combinations (same and different code groups, 0- and 256-chip frame timing offsets). These measurements were repeated for three different types of UE. The results show no distinct pattern to indicate that the performance of any given scenario is better or worse than another. Thus, it was concluded that the use of the same code groups and 0-chip cell frame timing offset does not affect UE camp-on time.

CONCLUSIONS

It is clear from the measurements that DL scrambling code planning can be used to enhance P-SCH and S-SCH performance. With careful code planning, it is possible to maximize code reuse while taking advantage of similar S-SCH code blocks by adjusting frame timing to gain some P-SCH and S-SCH E_c/I_0 coverage (up to 2 dB in the field in some cases).

It is also clear from measurements that this method of DL scrambling code planning does not degrade system performance at network registration, at call establishment, or during handover. In fact, it is expected that the technique may have other benefits not yet verified, such as improving detection of neighbors during soft handover. ■

ADDITIONAL READING

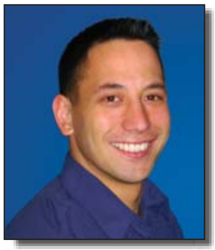
- R. Joyce, T. Griparis, M. Swinburne, and A. Rouz, "Orange/Fujitsu Wideband CDMA Field Trials – System Overview," *Proceedings IEE 3G2000 International Conference on Mobile Communication Technologies*, 2002, pp. 6–10.

BIOGRAPHIES

Thrasivoulos (Sakis) Griparis joined Bechtel in July 2004 and is currently involved in the acceptance and optimization of a new 3G network built by Bechtel in Australia. Before this, he worked for about 6 years with various vendors and operators around Europe, mainly on preparing and deploying new UMTS networks. Projects for clients such as Siemens in Germany; PT-Telecomm, OniWay-Telecomm, and Nortel in Portugal; and Orange UK (Nokia) required his involvement in bids, network planning, network acceptance, parameterization, network optimization, and trial setup and testing.

Previously, Sakis spent 3 years as a researcher at Fujitsu Research Labs, working on WCDMA technology. His activities included designing and testing a WCDMA digital beam former hardware test bed and performing UMTS pilot trial testing in Japan (NTT DoCoMo), France (Alcatel), and the UK (Orange). Sakis initially became involved with UMTS at the Kings College Centre of Telecommunications Research, where he did research on channel estimation techniques for WCDMA receivers.

Sakis holds a degree in Electronic Engineering from National Technical University in Athens and a master's degree in Telecommunications from Kings College, London.



Tristan Lee is a senior RF engineer for the rollout of a Bechtel 3G project in Sydney, Australia. Specializing in WCDMA, he is currently responsible for RF governance and UMTS optimization in Australia. Before joining Bechtel in May 2005, Tristan worked for Orange UK during its 3G rollout. There, he was responsible for UMTS optimization guidelines. Previous roles include research and innovation (telecommunications) and software development.

Tristan graduated from the University of Birmingham (UK) with a degree in Mathematics.