Application of the SAROTA index in real-life scenario

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Abstract. A unique parameter referred to as the SAROTA index which accounts for both the specific absorption rate (SAR) and the over-the-air (OTA) performance of a mobile phone was previously proposed to characterize the real-life exposure. The applicability of the SAROTA index was confirmed using SAR and total radiated power (TRP) data obtained under laboratory conditions wherein the power control (PC) enforced on the mobile phone was implemented artificially. Herein the investigation is extended to measurements conducted for the speech mode of operation in real-life scenarios. Based on the actual PC implemented during the communication with the base station, the instantaneous and average real-life exposure experienced by the mobile phone user is analyzed and compared to the predicted SAROTA index. To capture the PC in real-time, a set of hardware modified phones with embedded network monitoring software are used. The instantaneous uplink transmit power level (TX_LEV) along with various downlink parameters such as the receive signal level (RX_LEV) and received signal quality (RX_QUAL) of the communication link are thus available for performing a comprehensive RF exposure analysis.

1. Introduction

International guidelines have proposed the peak spatial-average specific absorption rate (SAR) as the metric to quantify the limit of radio frequency (RF) exposure due to mobile phones [1]. The procedure to evaluate the SAR compliance of mobile phones is described in international measurement standards [2,3]. For example, in European countries, the peak 10 g average SAR value of a mobile phone operated at the ear should not exceed 2 W/kg. In some countries, such as in France, it is mandatory that the actual SAR value be clearly displayed as information for the general public [4]. According to the current test procedures, the unique 10 g average SAR value actually corresponds to the maximum value obtained for various test configurations using the specific anthropomorphic mannequin (SAM) head phantom. Measurements are performed while the mobile phone is operated at the maximum power level for four intended use positions –left/cheek, left/tilt, right/cheek, right/tilt– at the centre frequency of a given operating band, following which additional measurements are performed at the two extreme frequencies of the examined band for the configuration which yielded the maximum SAR value. The same procedure is applied to all the operating frequency bands of the mobile phone and the displayed SAR value is the maximum obtained from all the test configurations. For a quad-band mobile phone –Global System for Mobile (GSM) communication 900 MHz, GSM 1800 MHz, Universal Mobile Telecommunication System (UMTS) 2100 MHz and Long-Term Evolution (LTE) 2600 MHz– a total of 24 elementary measurements are required to obtain the maximum 10g SAR value.
In real-life scenarios, the power emitted by the mobile phone and the frequency band of operation will be essentially dictated by the network operator [5-7]. Depending on the network condition at a given moment and location e.g. received signal level (RX_LEV) and quality (RX_QUAL), network load etc., the mobile phone may shift from one frequency band to another. A power control (PC) mechanism is also deployed so that the power emitted by the mobile phone is optimized to ensure an acceptable quality of the communication. Clearly, the average real-life exposure experienced by the mobile phone user will be relatively lower than the maximum 10 g SAR value measured under laboratory condition. Furthermore, the average real-life exposure will not only depend on the maximum 10 g SAR value but also on the over-the-air (OTA) performance of the mobile phone [8]. Both SAR and OTA data are therefore required to characterize the real-life exposure and the SAROTA index was previously proposed to account for both these parameters [9]. The applicability of the SAROTA index was previously investigated using SAR and total radiated power (TRP) data and the PC mechanism was simulated using a base station emulator [10]. Herein the investigation of the SAROTA concept is extended to real-life scenarios wherein the power control mechanism is dictated by the actual base station of a given network operator.

2. SAROTA

The SAROTA index is simply expressed as the ratio between the peak 10 g average SAR ($SAR_{\text{max}} \, \text{W/kg}$) and the $TRP_{\text{max}} \, \text{(W)}$ measured under laboratory condition for the same test configuration, i.e. same mobile phone position against the SAM head phantom, the same traffic channel and the same maximum transmit power level:

$$SAROTA = \frac{SAR_{\text{max}}}{TRP_{\text{max}}}$$  \tag{1}

The SAROTA index (kg$^{-1}$) provides a unique parameter to quantify the performance of a mobile phone in terms of both RF exposure and OTA performance. For example, it is predicted that a mobile phone with a high SAROTA index will lead to a relatively higher average real-life exposure than one with a low SAROTA index. It is also predicted that two mobile phones with the same peak 10 g SAR values but different TRP values will yield different SAROTA indices and consequently different average real-life exposures.

The average real life exposure ($SAR_{\text{real\_life}}$) can be derived from the SAROTA index as follows:

$$SAR_{\text{real\_life}} = SAROTA \times TRP_{\text{real\_life}}$$  \tag{2}

where $TRP_{\text{real\_life}}$ is the average TRP observed in real-life scenarios with power control mechanism enforced by the base station. It is deduced from the instantaneous power emitted by the mobile phone (TX_LEV).

3. Measurement Setup

Two sets of hardware modified mobile phones with embedded network monitoring software are employed for the study: set I consists of four samples of the same mobile phone model (labelled A1 to A4) and set II consists of three different mobile phone models (labelled M1 to M3). Since signal strength variations due to near vicinity object movement will be observed in a typical wireless network, the investigation is preferably undertaken in a closed indoor environment to minimize these variations and to gain insight of the PC mechanism experienced by the mobile phones. Set I is used to examine the stability of the results in this indoor environment which is an empty room containing only the measurement setup. Set II is then used to evaluate the real-life exposure due to the mobile phones placed against the right/cheek position of the SAM phantom as shown in figure 2. The measurements are performed for the GSM 900 MHz band with the mobile phones operating on three different
networks (referred to as A, B and C) chosen such that the combination of the RX_LEV and RX_QUAL levels are distinct for each network at the given location. To account for the instantaneous signal strength variations, the measurement time is set to 30 minutes and the mobile phones are configured to play an audio file for the uplink to prevent activation of the discontinuous transmission (DTX) mode.

Figure 1. Experimental setup inside the indoor environment: one mobile phone calls another one, with both mobile phones placed against the right/cheek position of the SAM phantom.

4. Measurement Results

Figure 2(a) shows the results of the RX_LEV and TX_LEV obtained for one network operator using the four samples of set I. As expected, since the electromagnetic environment is rather similar at the location for a given network, all mobile phones show similar received and transmit characteristics. To demonstrate the impact of RX_LEV on the TX_LEV, the OTA performance of one mobile phone was modified by simply sticking a metallic strip over the antenna location (A2_mod). Figure 2(b) shows that the RX_LEV is then relatively lower and consequently the TX_LEV increases.

Table 1 provides the results obtained using the three mobile phones from set II operating on the three different networks. Information about the propagation condition and the quality of a given network is gained from RX_LEV and RX_QUAL, respectively. TRP_real_life is representative of the overall network condition. For example, even when the received signal level is highest for network B (-70 dBm) with relative bad quality (2-4), the mobile phones emit at higher power levels and the average real-life exposure is then much higher indicating channel specific behaviour. Furthermore, SAR_real_life values are consistent with the values predicted using the SAROTA index i.e. the lowest real-life exposure is observed for the mobile phone with the lowest SAROTA index (M1).
Table 1: \( \text{SAR}_{\text{real-life}} \) on three different networks at the given indoor location.

| Network   | Mobile Phone Model | SAR\(_{\text{max}}\) (W/kg) | TRP\(_{\text{max}}\) (dBm) | SAROTA (kg\(^3\)) | Avg. RX\(_{\text{LEV}}\) (dBm) | TRP\(_{\text{real-life}}\) (dBm) | SAR\(_{\text{real-life}}\) (W/kg) |
|-----------|--------------------|------------------------------|-----------------------------|-------------------|-------------------------------|-------------------------------|-------------------------------|
| A (RX\(_{\text{QUAL}}\): 0) | M1                 | 0.155                        | 24.86                       | 4.05              | -74.5                         | 7.76                          | 0.024                         |
|           | M2                 | 0.299                        | 24.52                       | 8.44              | -79.4                         | 5.56                          | 0.030                         |
|           | M3                 | 0.685                        | 26.87                       | 11.3              | -77.5                         | 8.39                          | 0.078                         |
| B (RX\(_{\text{QUAL}}\): 2-4) | M1                 | 0.163                        | 26.60                       | 2.85              | -67.4                         | 20.48                         | 0.32                          |
|           | M2                 | 0.299                        | 26.77                       | 5.03              | -69.7                         | 21.64                         | 0.73                          |
|           | M3                 | 0.633                        | 26.49                       | 11.4              | -67.1                         | 21.54                         | 1.62                          |
| C (RX\(_{\text{QUAL}}\): 4-7) | M1                 | 0.222                        | 24.58                       | 6.17              | -81.2                         | 10.84                         | 0.075                         |
|           | M2                 | 0.292                        | 23.64                       | 10.1              | -78.6                         | 14.82                         | 0.31                          |
|           | M3                 | 0.692                        | 25.69                       | 14.93             | -78.7                         | 15.60                         | 0.068                         |

* RX\(_{\text{QUAL}}\) range 0-7, with 0 = best receive quality and 7 = worst receive quality

5. Conclusion
The applicability of the SAROTA index as an indicator of the real-life exposure due to mobile phones was investigated. The effect of the power control mechanism was characterized for three different networks at a given indoor location. The real-life TRP provides information about the overall network condition including the effects of both received signal level and quality. The real-life exposure is consistent with the predicted SAROTA index. Similar evaluation will be performed for the outdoor scenarios in the future.

6. References
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