PERFORMANCE EFFICIENT METHOD FOR SCATTERING REFLECTION PREDICTION IN MOBILE CELLULAR NETWORKS

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Abstract—The mobile radio channel in areas dominated by hills and mountains is frequency selective with severe time delay spread — up to 40–100µs is measured in Norway. A GSM mobile can utilize only 15µs of this channel, while the power laying outside this time window will be received as interfering noise. 1st order reflection calculations based on bistatic radar theory makes it possible to predict the channel response throughout base station coverage area, such that the areas with low signal-to-interference ratio can be detected. The method is successfully implemented and verified against measurements.

I. INTRODUCTION

The enormous growth in mobile cellular networks rises the need for reliable network planning tools to speed the process from network design to network implementation. Many macro radio coverage planning tools include simple path loss prediction algorithms [1–6], including prediction of diffraction loss and clutter loss [9–11]. These algorithms give good prediction for flat and modest rolling areas.

However, for all areas dominated by hills and mountains, these algorithms will fall short of giving good coverage prediction. This is due to reflections from the hilly terrain creating a complex multipath radio channel with severe time spread. The length of this channel can be 40µs and more, while the GSM mobile can utilize only a 15µs window. The received signal quality will suffer if the power inside and outside this window is comparable. In other cases reflected power can enhance the signal quality.

An efficient method for 1st order reflection prediction is proposed based on bistatic radar theory, giving the channel response throughout a coverage area. This makes it possible to predict the total signal level, as well as calculating the signal-to-interference ratio. The predictions are compared against GSM measurements.

II. 1ST ORDER REFLECTION PREDICTIONS

A. The Mobile Channel

There are three contributors to the mobile radio channel between the base station and a mobile unit placed at a point in the terrain:

1. Direct path between the two antennas.
2. Signals reflected close to the mobile unit (in principle just as well close to the base station, but usually close to the mobile and we will refer to it as so in the rest of the paper).
3. Signals reflected further away from the mobile unit.

Referring to 1. as having no delay, signals in 2. will have a small delay compared with the time resolution of the system and a random phase. 1. and 2. add up to what we will call a “semi direct path” with flat Rayleigh fading (Rice if the direct path is of importance). The signals in 3., which we will refer to as the reflected signals, have a large number of reflectors with different placement and time delays and thereby introduce a time spread. The three contributions will sum up to a frequency selective fading channel.

B. Coverage Calculations

Given data about a base station (placement, antennas, power) the receiving conditions are calculated at any point in the terrain around the base station. Receiving conditions include signal power level and time spread, i.e. the channel impulse response. The semi direct path to a given point is just the transmitted power subtracted the path loss and the “clutter loss”. The latter term is the loss typical for the type of terrain at the given receiver location (e.g. mountain, forest, suburban, urban etc.), while the path loss is calculated based on the terrain profile between the base station and the given point in the terrain. There exist several algorithms for calculating the path loss based on a terrain profile in mobile communications ([1–6], and special multiple-edge diffraction loss solution [9–11]). The reflected signal path goes from the transmitter to the reflection areas, and finally to the receiver. A reflection area is a terrain surface which is illuminated by the transmitter and is oriented in such a way that reflections from it hit the receiver. The reflections will be diffuse reflections — this gives a high reflection loss which is why second and higher order reflections will not be taken into account. The total loss is given by the path loss between transmitter and reflection area, the reflection loss, the path loss between reflection area and receiver, and the clutter loss at the receiver location. There will be one contribution from each reflection area, with a time delay given by the placement of the reflection area. Summing up the semi direct path and all the reflected paths, including information about the different delays, the time response of the channel is constructed. The path losses and the clutter loss of the reflected signals can be calculated the same way as for the semi direct path. Reflection loss will be calculated based on bistatic radar theory.

C. Bistatic Radar

The reflection from the terrain in mobile communications is identical to "terrain clutter" in bistatic radar [12] (a radar with the transmitter and the receiver at separate locations). Skolnik [13] has shown the connection between transmitted and received, reflected power. Received power is given by

$$P_R = \frac{P_T G_T G_R \lambda^2 \sigma_Q}{(4\pi)^3 d_{TQ}^2 d_{QR}^2 L_{TQ} L_{RQ}} \tag{1}$$

where

- P received and transmitted power,
- d distance (transmitter T, reflection area Q, receiver R),
- G antenna gain at transmitter and receiver,
- λ wave length,
- σ_Q bistatic radar cross section for the reflection area,
- L transmission loss in excess of free space loss.

The bistatic radar cross section σ_Q is decided by the reflection area size, orientation, and type of terrain. It is common to refer to a size independent cross section

$$\sigma_Q^\circ = \sigma_Q / A_Q . \tag{2}$$

When the signal from the base station hits the reflection area, the reflected signal is spread into every possible direction. These directions can be divided into groups. The two most important "direction groups" defined by [13] are the back scatter region and the forward scatter region. A geometrical study reveals that the latter one, containing among other the specular reflection component, only is of interest for reflection areas close to the mobile. The effects of these reflections are taken into account by the "semi direct path" models [7]. Looking at reflection areas further away from the mobile unit, the forward scatter is "hitting the sky" while the back scatter reflection can hit other parts of the terrain far away from the reflection area. If the reflection area is described by the *xy* plane in Fig. 1, the back

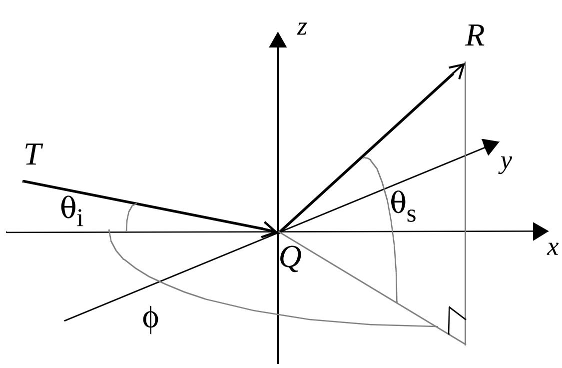

Fig. 1 Bistatic radar angles. Signal coming from transmitter T and reflected at Q, then transmitted further to receiver R.

scatter region is limited by ϕ in the region ±40° and θ_s between 0° and 90°. Inside this region the size independent bistatic radar cross section can be described as

$$\sigma_Q^\circ = \gamma(\sin\theta_i \sin\theta_s)^{1/2} . \tag{3}$$

With γ only dependent on type of terrain, σ_Q° is a function of the angle of arrival θ_i and the scatter angle θ_s. Calculations will not be performed on surfaces where the angles are not inside the specified area, since it will not give significant contributions to the results.

D. Calculated Signal Quality

The result of the calculations is a "raster map" covering a pre-chosen area. Each "pixel" contains the channel response at the given point and can be used for calculations of signal quality in that position. A real GSM receiver picks out the 15 µs window which maximises the power. In the same way a window is slid over the calculated channel response and an optimum placement is found in each point. The signal power level will equal the power inside the window. The signal power inside and outside these 15µs give a signal-to-interference noise ratio, called Q_{15} in GSM terms. Low Q_{15} values give unacceptable quality, even when the total received signal power is high. It is now possible to display both a signal level map which indicates if the signal level is sufficient, and a Q_{15} map to detect areas with high interference level. Timing advance in GSM is the total delay between transmitter and receiver. This should equal the calculated window position plus direct propagation time between transmitter and receiver and can be used for model verifications.

III. PREDICTIONS COMPARED TO MEASUREMENTS

A. Measurements

GSM measurements along main roads were performed by *NetCom GSM AS* in several areas in Norway. The measurements are of type TEMS version 3 (a format of Ericsson) including GPS co-ordinates, received signal level (denoted *rxLev*), received signal quality based on Viterbi metrics (denoted RX_{QUAL}), and absolute timing advance (*TA*). However, no channel responses were measured — thus the predicted channel responses must be verified against measured RX_{QUAL} and *TA*. RX_{QUAL} can be compared to Q_{15} values using relationship given in Table 1. The GPS co-ordinates have accuracy of ±100 meters. Co-ordinates are stored every 50–100 meter. The road is assumed linear between these location stamps. Measurements of *rxLev* are averaged within each digital map grid location when compared to predictions, because the predictions give one result for each grid, while the measurement log-file might have 1–40 measured signal values within each grid. The grid size is approximately 100 times 100 meters.

Table 1 Relationship between Q_{15} and RX_{QUAL} at high received signal power [14].

Q_{15} [dB]	RX_{QUAL}	Signal quality
< 9	6–7	Bad
9–11	4–5	
> 11	0–3	Good

B. Investigated Sites

In this paper the focus is on three Norwegian GSM sites.

1) Florø: a GSM base station on the western part of Norway. The measured path is along a tongue of land, surrounded by high mountains some 1–3 km further north and south (Fig. 6). The signal strength is high, but the channel responses are so long that low Q_{15} values give many trouble areas.

2) Tretten: is located in a narrow valley just north of Lillehammer, the host city for the Winter Olympics ‘94. The valley is reflecting signal power into a deeply shadowed area, and thus GSM coverage is obtained without adding another site.

3) Røyse: is located just north-west of Oslo. The measured path is slightly shadowed (more in real terrain than given by the digital map), and a mountain reflects signal power back and produces low Q_{15} values.

C. Analysing the Results

In Fig. 2–4 measured values are given as solid lines, predicted signal level in dashed lines, direct-only predicted values in dash-dot, and *TA* equal to direct distance between transmitter and receiver as dotted lines. The units for RX_{QUAL} are 0–7, and in dB for Q_{15}. The *TA* unit equals 546.9 meters, or 1.8µs.

1) Florø: There were almost no severe shadowed areas — that is the reason why the standard deviation (std) has almost no improvements comparing direct-only predictions to reflection-including predictions. However, the predictions signalled many areas with low Q_{15} values (Fig. 6). These were confirmed by the high values of the measured RX_{QUAL} parameter. The results can be viewed in Fig. 2. Fig. 2a shows that the predicted *rxLev* follows measured values closely, but at the ending part the differences are big. This is due to the measuring van driving through urban areas, and there is bad consistency between the map and the real terrain[1]. The *TA* values are following the physical distance between the base station and the mobile, except a very few places — this is confirmed by the predictions in Fig. 2c.

2) Tretten: Here there were areas with severe shadowing at the end of the measured path, so the direct algorithm predicted low signal power, as seen by Fig. 3a. However, a local mountain is producing reflected signal power, and the measurements and reflection predictions show high enough signal power to give

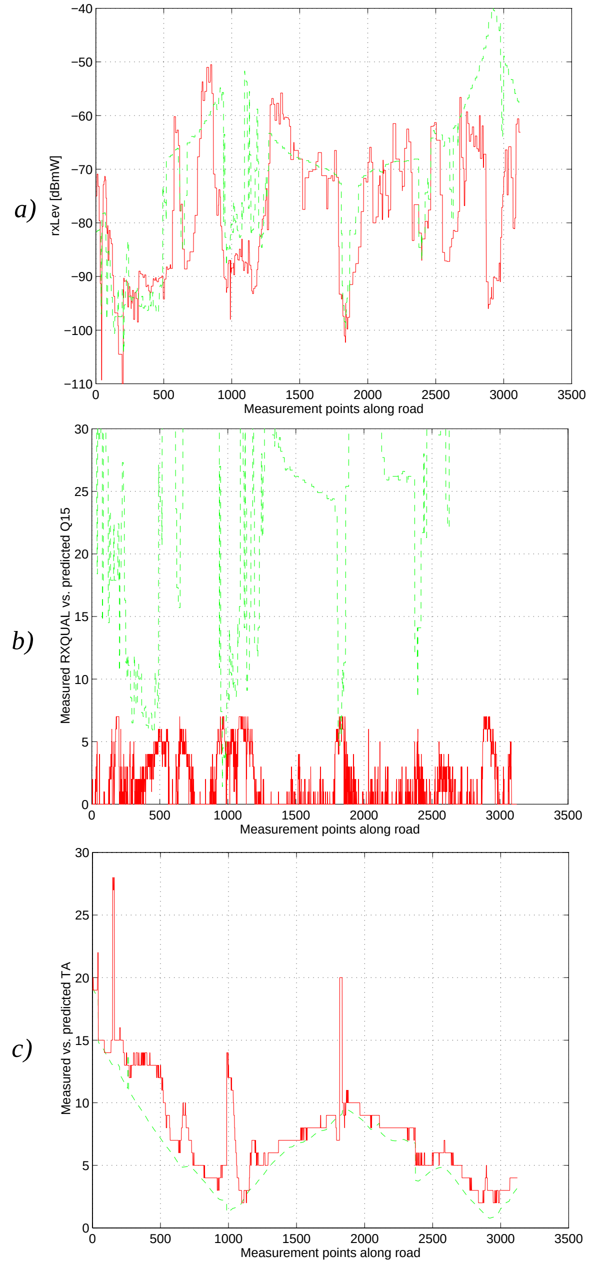

Fig. 2 Florø comparison. *a)* Measured vs. predicted signal power. *b)* Comparison between measured RX_{QUAL} and predicted Q_{15}. *c)* Measured vs. predicted *TA*

acceptable GSM coverage (approx. –90dBm). The measured and predicted TA confirm it is reflected power (Fig. 3c).

3) Røyse: This site is not easy to predict due to differences between real terrain and the provided digital map. The first 90% of the measured path is in constant NLOS (non-line-of-sight), while the digital map gives only approximately the first 30% of the path in constant NLOS. This gives prediction errors up to 15dB caused by the nonexistent LOS path (Fig. 4a). Looking at the calculated channel response for two chosen points (Fig. 5), one is predicted with LOS (A) and one without (B). In (A) a suppression of the direct path would have given agreement for both signal level, Q_{15}, and timing advance. In (B) there is agreement. This shows that the reflection calculations are cor-

1. The maps used have no building height information (really, grid size of 100 times 100 meters makes that of less value). The prediction algorithm therefore have LOS to the base station (-40dBm predicted), while there is NLOS in real terrain due to buildings.

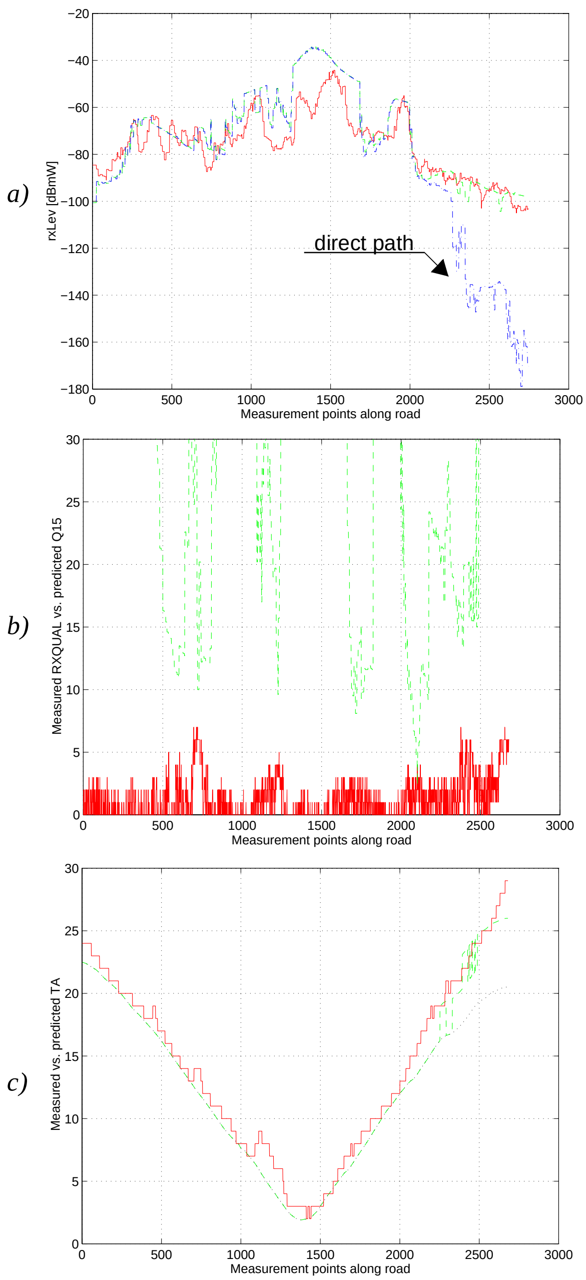

Fig. 3 Tretten comparison. *a)* Measured vs. predicted signal power. *b)* Comparison between measured RX_{QUAL} and predicted Q_{15}. *c)* Measured vs. predicted *TA*

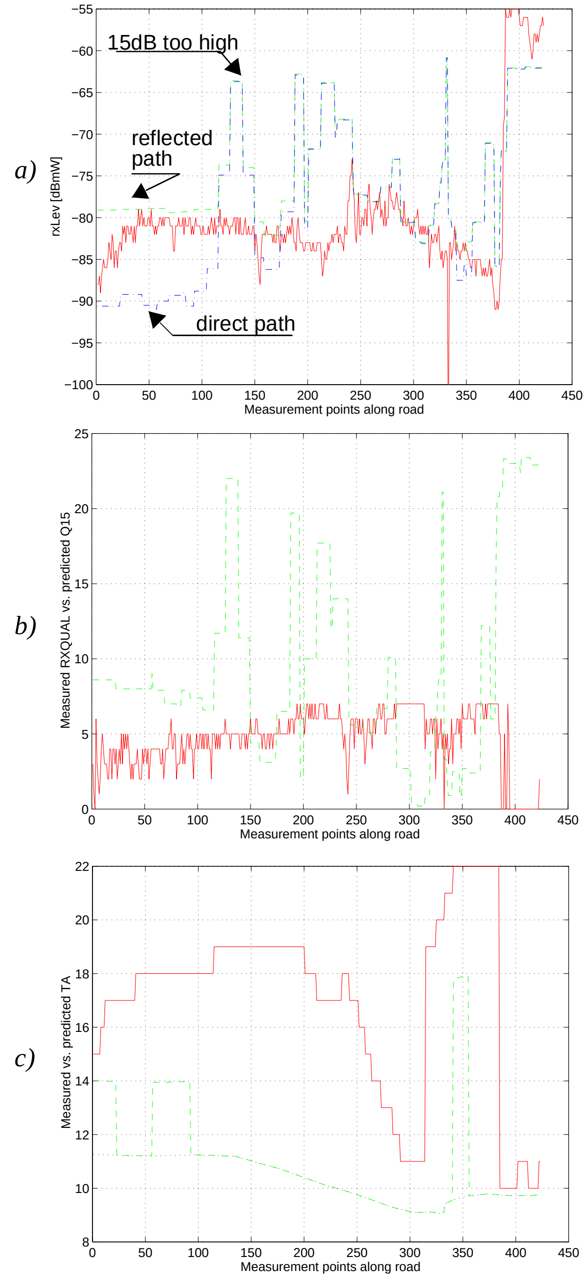

Fig. 4 Røyse comparison. *a)* Measured vs. predicted signal power. *b)* Comparison between measured RX_{QUAL} and predicted Q_{15}. *c)* Measured vs. predicted *TA*

rect for both cases, and less vulnerable to map inaccuracies than the direct path calculations.

D. Statistical Results of Received Signal Power

The algorithm described in Section II was implemented with 5µs channel response time resolution. Table 2 shows the statistical results of the error between measured and predicted *rxLev* values, based on Fig. 2a–4a. For the Florø and Tretten sites, the predictions close to the base stations are left out of the statistics, due to large differences between real terrain and map. Note that the std is improved by 14.3dB at the Tretten site, comparing reflection predictions to direct-only predictions.

Table 2 The std and mean error of the predictions

Location	Direct std [dB]	Direct mean [dB]	Reflected std [dB]	Reflected mean [dB]
Florø	9.4	-2.5	8.9	-3.4
Tretten	21.5	9.1	7.2	-1.5
Røyse	8.7	-1.5	6.6	-4.7

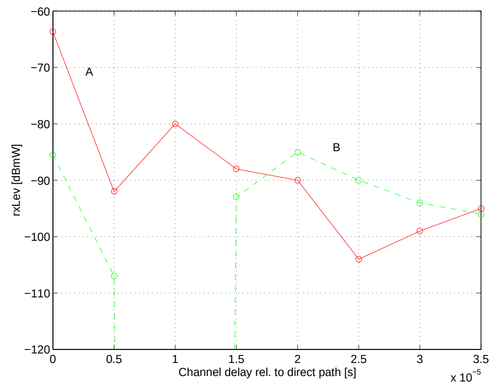

Fig. 5 Channel response profiles at Røyse, measure # 133 (solid) and 348 (dashed). The direct component at (A) is -63dBm. A suppression of approximately 20dB would have given agreement with measurements. At (B) the prediction is correct.

E. Computational Performance

All calculations were done on a HP workstation 9000/720 (SPECfp95=2.03, SPECint95=1.57, or approximately Pentium 90). Because of a reflection area filtering algorithm, the computational load is highest when running predictions in hilly terrain, and lowest in flat terrain. The three chosen sites in this paper all belong to the "hilly-terrain" group — the Florø site has however twice the reflection density compared to the other two sites, as revealed in Table 3.

Table 3 Computational time

Site	Area size [km^2]	CPU time [s]	Time pr grid location[a] [ms]	Reflection density [km^{-2}]
Florø	518	5660	109.3	1.25
Tretten	439	2900	66.1	0.48
Røyse	298	1650	55.5	0.43

a. approx. grid-size 100 times 100 meters

IV. CONCLUSION

Reflections in mobile communications can create long channel responses. This can cause either (A) poor signal quality due to low signal-to-interference ratio or Q_{15} in areas with adequate signal strength, or (B) adequate signal strength in areas with deeply shadowed direct signal component. The proposed method has verified to detect both cases. At the Florø site (A) all areas with bad signal quality were predicted with low Q_{15} values. At the Tretten site (B) adequate GSM coverage was predicted in a narrow and deeply shadowed valley in accordance with measurements. Correct detection of LOS or NLOS revealed its importance for accurate Q_{15} prediction at the Røyse site — the success of this depends on map accuracy. The method proves to be computational efficient since equations are of low complexity, and only illuminated areas of the terrain are used for reflection path loss predictions.

ACKNOWLEDGEMENT

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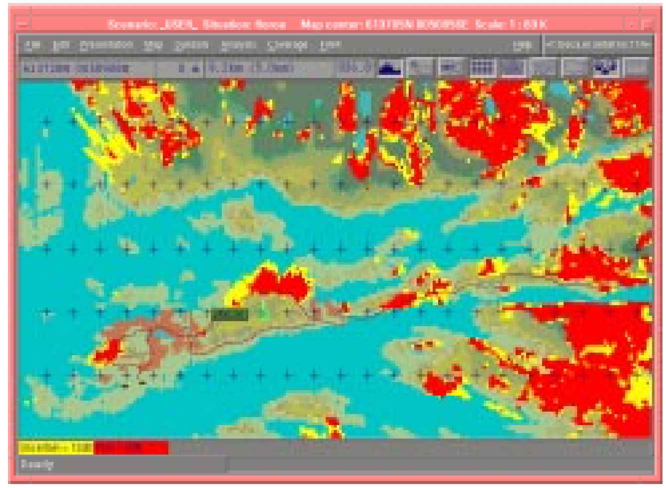

Fig. 6 The ASTRIX user interface, showing site Florø and the Q_{15} prediction results. Low Q_{15} values are shown by the dark areas (red). Measured path is seen as solid (brown) line.

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