An adaptive antenna for the NMT 900 mobile telephony system.

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Abstract: **An adaptive antenna for the receiver base station of the NMT 900-system has been designed at the Circuits and Systems Group, Uppsala University. The properties of the antenna has been evaluated by Telia Research AB. In this paper the work involved in the antenna design and the field tests is reported.**

I. INTRODUCTION

The number of users in mobile telephony systems has increased dramatically over the last years. With more users the risk for interference between the channels increases, since the number of usable channels is always restricted due to the limited frequency spectrum available. In order to reduce the risk for interference and increase the traffic capacity of the system the introduction of antennas with directed beams has been proposed, cf.[1]. To obtain the best spectrum efficiency these lobes should be as narrow as possible which makes adaptivity necessary in order to track the movements of the mobile telephone terminal.

Adaptive antennas has successfully been used in several different applications such as radar, sonar and satellite communications. However only a few experimental investigations using adaptive antennas in mobile telephony have been made.

The aim with the antenna reported here has been to obtain a system which allows experiments in order to estimate the traffic capacity and speech quality. Another important issue was to gather experience in order to develop the technology and make more advanced antennas possible, which will increase the benefit of introducing adaptive antennas in mobile telephony.

II. ANTENNA DESIGN

The adaptive antenna consists of four quarter wave antenna elements in conjunction with four receivers, see Fig. 1. The signal is received by the antennas and the direction of arrival is estimated by a simple phase comparison between the antennas. The phase shifts, Φ_{1-3} in Fig. 1, between the antenna elements controls the

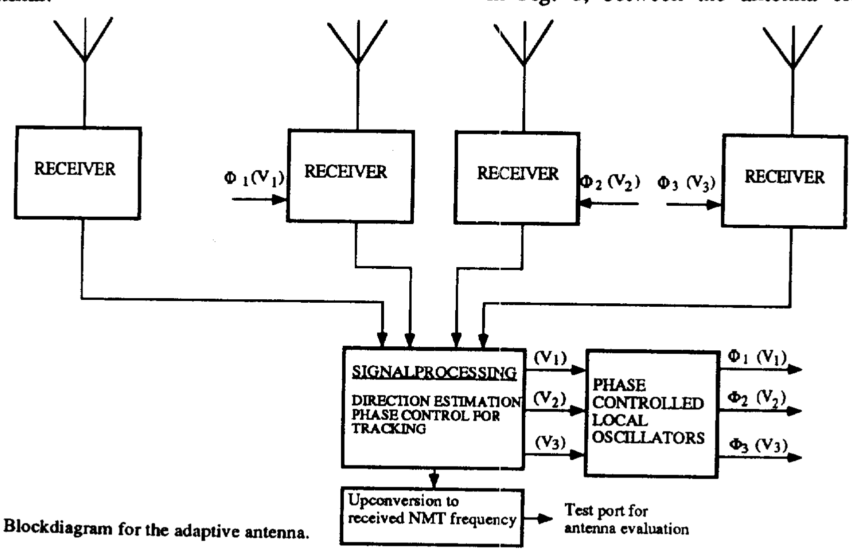

Fig. 1. Blockdiagram for the adaptive antenna.

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pointing angle of the lobe, by varying the phase of the receiver local oscillator respectively. Using this novel way of controlling the phase of each element makes it possible to direct the phase plane of the antenna continuously [2]. The local oscillators in each receiver respectively are realized as phase locked loops, PLL. By varying the control voltages, V_{1-3} in Fig. 1, to each PLL the phase shift for each element can be controlled within ±240 degrees. The voltages V_{1-3} are proportional to the outputs from the phase comparison of each received signal. This forms a closed loop and the antenna beam will follow the direction of arrival of the received signal.

There are four identical receivers, one for each antenna element. Great care was taken to reduce the variation in phase and amplitude characteristics of the receivers. The phase of the IF signals are compared in pairs and filtered to generate the voltages V_{1-3}. The IF signals are also added together to get the wanted beam for the output of the received signal, see Fig. 1. In order to simplify the evaluation of the antenna, the added signal is transformed back to the received NMT frequency. It can thereby be connected directly to the input of an ordinary base station.

III. THE ANTENNA ARRAY

The antenna array consists of four quarter wave antenna elements placed in a square with the side equal to a quarter of a wavelength (~33 cm). This configuration was selected since it has the advantage that every angle of arrival produces an unique set of phase differences between the elements, and the distance between the antennas is small enough to avoid any grating lobes. Theoretical radiation patterns are shown in Figs. 2 and 3.

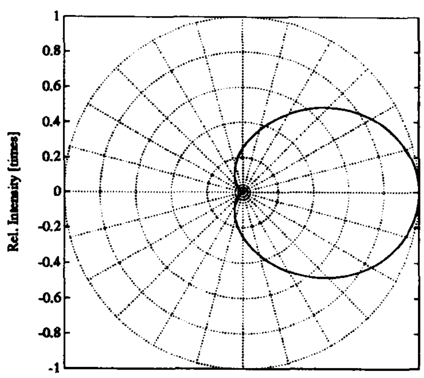

Fig. 2: Theoretical radiation pattern. Polar diagram.

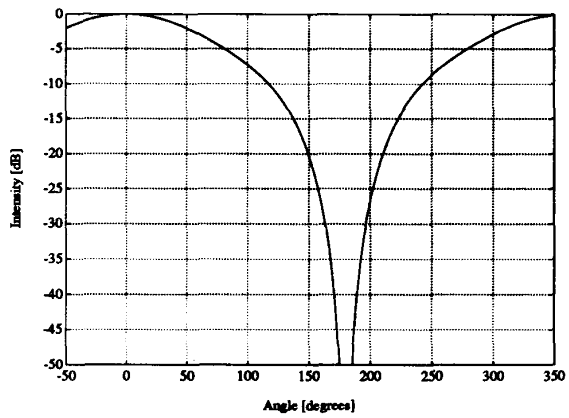

Fig. 3: Theoretical radiation pattern in decibel. The lobe is locked in 0 degrees.

Our adaptive antenna is not limited to this array configuration only. The antenna array can be configured to any form consisting of four elements.

IV. RESULTS

The properties of the antenna have been evaluated. Many different tests have been performed. In the tests a non-directive reference antenna (quarter wave antenna element) was situated beside the antenna array. This gave the possibility to compare the adaptive antenna with an non-directive one. During the tests, the mobile which were transmitting the desired signal and the caravan containing the receiving antennas where equipped with GPS (Global Position System) receivers. The direction to the mobile could then be computed.

As mentioned before the output of the adaptive antenna has the same frequency as the received signal. This enables the possibility to connect the antenna directly to an ordinary NMT base. The adaptive antenna will than function as a pre-stage to the base.

A. Following of a mobile

To check that the pointing angle of the beam is locked in the wanted direction the control voltages, V_{1-3} in Fig. 1, were measured as the mobile was moving in the area around the antenna. The measured voltages were afterwards compared with values measured in an echo free room. The result for one of the voltages is shown in Fig. 4. Since the phase shift for each element can be controlled within ±240 degrees there is an ambiguity in the control voltages for each fix angle of the direction of arrival.

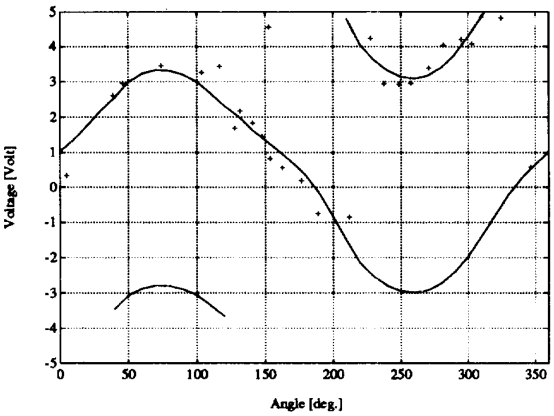

Fig. 4: One of the three control voltages versus the angle of arrival of the desired signal. The solid curve represents the values from a measuring in a echo free room. The + marks represent the values from the antenna evaluation.

The transmitting mobile had to be stopped each time the control voltages were to be measured. Otherwise the voltages tends to be unstable due to fading. Even when there was a clear line of sight between the moving mobile and the receiving antenna, the multipath was strong enough to make the phase differences unstable. Due to this instability of the phase front, an antenna with a narrow beam has to be adaptive in order to follow the variations of the phase front.

B. Cancelling of an interfering signal

The main reason for introducing adaptive antennas in a mobile telephony system, is the possibility to suppress interfering signals with different angles of arrival than the desired signal. The degree of suppression is decided by the antenna radiation pattern, se Figs. 2 and 3. The more narrow the beam is the better the interference rejection gets.

To test the adaptive antenna against co-channel interfering signals, another mobile transmitting a signal at the same frequency was added. As a comparative measurement the non-directive reference antenna located beside the antenna array was used. The results of the measurements are illustrated in Figs. 5 and 6.

During this test, only the mobile transmitting the desired signal was moving and very slowly. The other mobile was stationary in an angle of about 180 degrees away from the lobe maximum, Fig. 7. This resulted in a very smooth behaviour of the Carrier to Interference ratio (C/I). Frames consisting of 166 digital symbols were

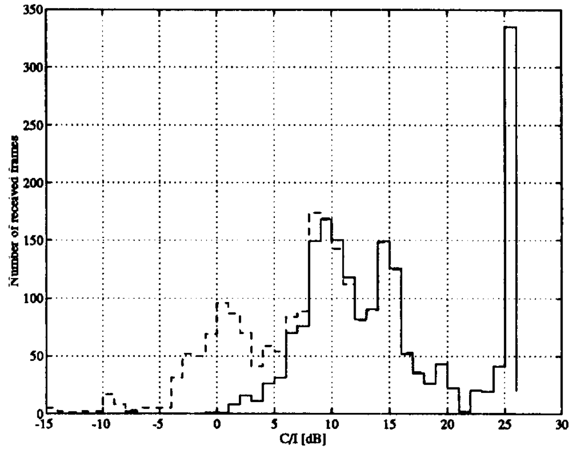

Fig. 5: Number of received frames as function of the Carrier to Interference ratio (C/I). The broken line represent the adaptive antenna. The adaptive antenna and the reference received equal many frames at C/I >10, but at low C/I the adaptive was much better than the reference.

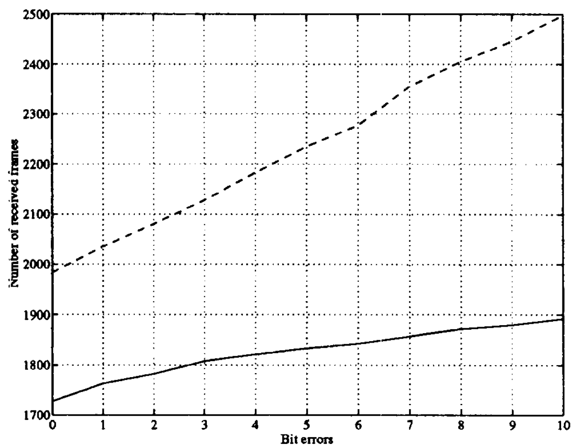

Fig. 6: Number of received frames versus the number of bit errors in each frame, for the adaptive (broken line) and the reference antenna. The number of bit errors are detected out of the 140 information bits in each frame. The number of received frames are cumulative, i.e. it shows the number of frames at a certain C/I plus the number received at lower C/I.

transmitted. As a measure of the transmission quality the number of frames received and their number of bit errors, were used. The adaptive antenna was able to receive frames down to C/I = -15 dB but the reference antenna broke down at 0 dB, see Fig. 5. (The signals involved in these tests are strong relative to the receiver and surrounding noise.) The reason is that the interfering signal gets attenuated about 15 dB due to the angle of arrival.

As is seen from Fig. 6 the adaptive antenna received about 30 % more frames than the reference. Half of these had not a single bit error. (Note that the number of frames in Fig. 6 are cumulative.)

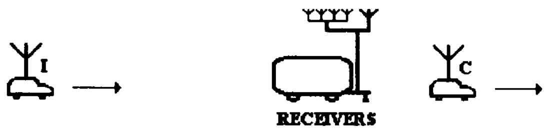

Fig. 7: The figure shows how the mobile transmitting the interfering signal was placed 180 degrees from the beam maximum. C was moving away from the receivers. I was moving towards them or not moving at all (different tests).

The measurements was repeated but now both of the mobiles were moving and with a higher velocity then in the former test. Fig. 8 shows C/I as the two transmitting mobiles were moving. Since there is no possibility to measure the values of C and I on the same channel, C and I were determined on channels nearby.

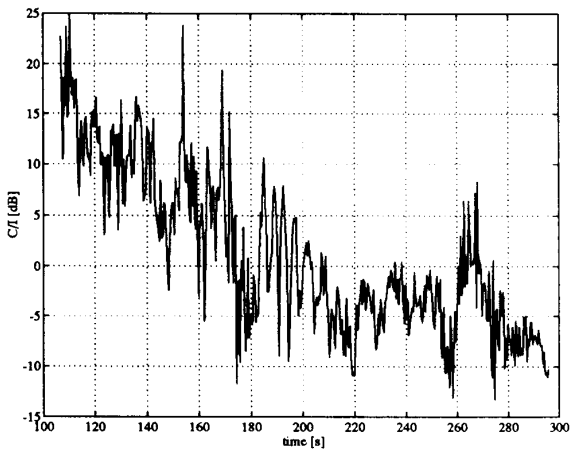

Fig. 8: The figure illustrates how C/I (Carrier to Interference ratio) varies in time when the two transmitting mobiles are moving slowly.

Since our adaptive antenna can not distinguish between the desired and an interfering signal on the same frequency, it will always lock on the strongest, i.e. the strongest after considering the attenuation due to the radiation pattern. As seen in Fig. 8 the C/I will change dramatically with time due to fading. Even if the transmitted interfering signal is weaker than the transmitted desired one (C/I > 0) the receiving base station can for a short moment experience the alternative ratio (C/I < 0).

In this test the reference antenna received slightly more frames than the adaptive, Fig. 9. The adaptive antenna was not locked on the desired signal all the time since the negative peaks of C/I were very deep. Both mobiles were moving resulting in fading of the signals. If the C-signal is having a negative peak at the same time as the I-signal is having an positive one, the adaptive antenna will lock on the interfering signal (even if the mean C/I is much higher than zero).

In an more realistic case the mean C/I should not get lower than about 15 dB. In this case only the peaks get bellow 0 dB and the adaptive antenna would be locked on the desired signal. Such a measurement will be conducted during spring 1994. In addition it would be desirable to get a more narrow beam i.e. more antenna elements, in order to attenuate the interfering signals more.

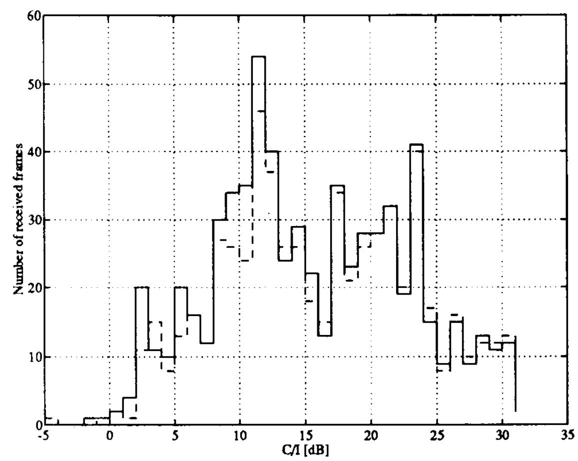

Fig. 9: Number of received frames as a function of C/I. In this test both of the mobiles where moving. The broken line represent the adaptive antenna. The total number of received frames for the antennas were approx. the same.

C. Measure of the sensitivity

The adaptive antenna is so designed that the signal strength of its output has the same value as the input to each receiver. Additionally, during the testing each input signal to the adaptive antenna were attenuated 6 dB to compensate for the gain due to the four receivers. This gave us the possibility to compare the two antennas with each other.

In this test we removed the interfering mobile. Our intention was to determine what would happen when only the desired signal was present. Fig. 10 shows the result. The signal strength was measured on the non-directive antenna.

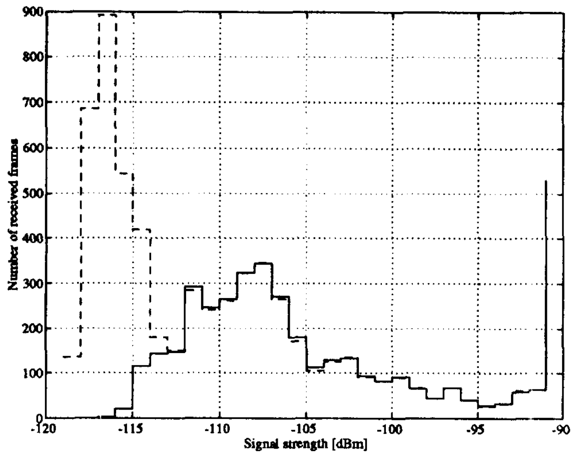

Fig. 10: Number of received frames versus the signal strength. The adaptive antenna (broken line) received more frames than the reference when the signal strength was low.

It is easy to see that the adaptive antenna is superior the non-directive antenna at low signal strength. Since we have compensated for the antenna gain, this shows that the dominating noise comes from the surrounding and not from the receivers. (The adaptive antenna will suppress the noise from the surrounding.)

V. CONCLUSIONS

The adaptive antenna is able to improve the transmission quality considerably.

A mechanism for distinguish between wanted and not wanted signals is necessary.

A narrower beam is preferred.

VI. REFERENCES

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