Emergency Positioning by TDOA/DF with Helicopters

Timo Hongell [1]

[1] ***Centre for Wireless Communications***
Department of Electrical and Information Engineering
University of Oulu
PL 4500 90014 University of Oulu Finland
Email: timohong@ee.oulu.fi

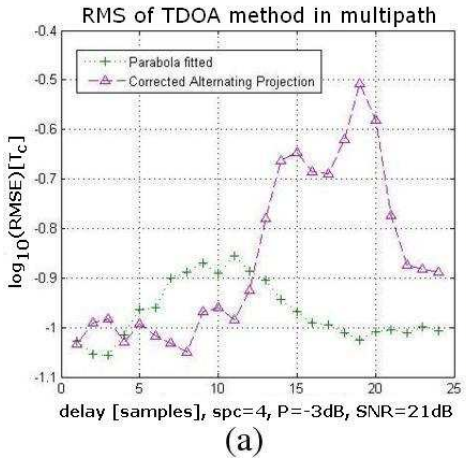
INTRODUCTION

Cell phones are used all over the world by millions of people. Therefore, locating a person's cell phone has become important especially in disaster situations such as avalanches, forest fire situations and collapsed buildings, where victims need to be found quickly and reliably. The goal of this paper is to study the time of arrival (TOA) and time difference of arrival (TDOA) direction finding (DF) and positioning methods in single and multipath cases for the Global System for Mobile Communications (GSM), Terrestrial Trunked Radio (TETRA) and Universal Mobile Telecommunications System (UMTS) systems. The performance and achievable DF and positioning accuracies of these methods are studied in different situations from various perspectives, one being helicopter based DF. The work is as a part of the European Commission Sensors for Terrestrial and Airborne Radio-Transmitter Rescue Search (STARRS) FP6 N^{o} 033742 project. https://www.research-projects.org/projects/starrs

NUMERICAL RESULTS

A traditional way to measure TOA or TDOA is the correlation process but that is not optimal for multipath channels. Instead, superresolution algorithms like those based on the maximum likelihood (ML) method should be used. In this project correlation and ML based estimators have been implemented using Matlab. The one based on ML was optimized for two path channels (while the correlator is optimal for a single path channel) and implemented by the alternating projection algorithm [1]. The estimators measured either TOA in a sensor or TDOA between the two sensors. The simulated signal is highly oversampled "analog" signal, which is sampled with a minimum of two samples per pulse. For that reason, the signal model is not exact, but more close to real life signal. Exact signal model would give better results. Simulation results were converted to match GSM, TETRA and UMTS systems such that TOA and TDOA performance of those systems could be predicted. The simulator gives TOA and TDOA results that are relative to chip length. In the result tables the usual method is a matched filter (MF) with the parabola fitted interpolation method and the AP method is parabola corrected alternating projection method.

A snapshot of numerical results is shown in Fig.1. It can be seen that the UMTS system is the most usable in terms of positioning. The achievable accuracies are around ten meters, which is suitable for positioning using RTT measurements and triangulation. The results achieved with GSM showed that GSM signals are useful only for large scale positioning situations, where the positioning error can be over 100 meters, such as large forest fires. In the case of TETRA signals the pulse duration is too long, which causes positioning inaccuracies of over one kilometer, clearly making TETRA signals useless for positioning.



SNR=18dB accuracy in meters [m]

multipath power	delay	GSM		TETRA		UMTS		AP-improvement
[dB]	[Tc]	usual	AP	usual	AP	usual	AP	
non	1/4	123,2	149,2	1853,3	2244,6	8,7	10,5	21,14 %
0	1/4	91,0	115,9	1369,1	1744,0	6,4	8,2	27,47 %
0	½	97,3	109,3	1463,4	1644,6	6,9	7,7	12,34 %
0	3/4	98,6	118,2	1483,0	1778,1	7,0	8,3	19,88 %
0	1	130,9	118,5	1969,5	1783,4	9,2	8,4	-9,44 %
-3	1/4	101,0	107,2	1519,0	1612,7	7,1	7,6	6,18 %
-3	½	106,7	112,2	1605,3	1687,9	7,5	7,9	5,16 %
-3	3/4	115,9	112,8	1744,0	1697,7	8,2	8,0	-2,67 %
-3	1	149,1	149,7	2244,1	2251,9	10,5	10,6	0,34 %
-6	1/4	143,9	140,9	2165,0	2120,1	10,1	9,9	-2,07 %
-6	½	146,9	138,0	2210,3	2077,1	10,4	9,7	-6,05 %
-6	3/4	133,3	143,1	2005,2	2153,0	9,4	10,1	7,40 %
-6	1	122,5	149,3	1842,7	2245,7	8,6	10,5	21,89 %
-10	1/4	103,8	124,3	1561,2	1869,6	7,3	8,8	19,84 %
-10	½	115,1	129,0	1732,4	1941,6	8,1	9,1	12,16 %
-10	3/4	120,9	141,5	1818,6	2128,4	8,5	10,0	17,12 %
-10	1	140,0	151,8	2106,0	2283,8	9,9	10,7	8,43 %

AWGN, 2-path

(b)

Figure 1: (a) RMSE of TDOA estimate error vs. delay, example results for the analysis. (b) TDOA simulation results with SNR=18 dB showing the achieved accuracy in meters.

CONVERTING RESULTS TO BEARING ANGLES

The achieved delay estimation results can be converted to bearing angle values. Using the standard deviation of delay, it is possible to define the standard deviations of the bearing angles related to them. It can be seen from Fig. 1 that in the very best case the standard deviation of the delay estimate is about $\Delta D = 0.05 T_{\mathrm{c}}$. For example, in the UMTS case, when the delay error is 4 meters, this leads to the calculation

$$\mathrm{error} = 0.05 \cdot T_{\mathrm{c}}[\mathrm{UMTS}] = 0.05 \cdot 0.26 \mu\mathrm{s} \cdot c = 4\ \mathrm{m}, \tag{1}$$

where c is the speed of light. It is now possible to estimate the bearing accuracies based on these results. Let the antenna separation be $L = 5$ m, which is suitable for helicopter based antenna placement. Transformation of parameters equation [2] is used to calculate the standard deviation of the bearing. The achieved bearing accuracy is $\pm\ 74.4^o$. A proper estimation range is $\pm\ 50^o$ around 0^o, which is the true target direction. Now, even in the best case the estimation range is over that. The only thing that is archived is a sector of about 150^o where the transmitter could be situated. For the GSM and TETRA systems this sector is uncountable since the standard deviations of the errors are much larger than five meters. Based on this it is clear that the TOA and TDOA methods are not suitable for direction finding with these systems. The bearing estimation would become reasonable if the used system would have higher transmitting bandwidths, as in the positioning case.

CONCLUSIONS

The simulation results and calculations showed that only UMTS signals provide adequate accuracies for positioning purposes. Round-trip time triangulation can be used to locate and track UMTS mobile sets and GSM phones, if the accuracy doesn't need to be that good. None of the studied systems are suitable for direction finding with helicopters.

References

[1] H. Saarnisaari and V. Tapio, "A Simple Multipath Delay Estimator Based on Alternating Projection Algorithm," *In: IEEE/ION Symposium on Position, Location and Navigation*, pp. 1086–1093, April 25–27 2006.

[2] Steven M. Kay, *Fundamentals of Statistical Signal Processing: Estimation Theory,* Prentice-Hall PTR, Inc. A Simon and Schuster Company, Upper Saddle River, New Jersey 07458, 595 p., 1993.