

RECOMMENDATION ITU-R SM.1598

**Methods of radio direction finding and location
on time division multiple access and code
division multiple access signals**

(Question ITU-R 28/1)

(2002)

The ITU Radiocommunication Assembly,

considering

- a) that the considerable expansion of cellular radiotelephony networks increases the risk of interference within networks and to networks, especially in the boundaries of countries at the edges of station coverages operating by different operators and/or in the case of sharing frequency bands or adjacent bands;
- b) that the maintenance of a high level of quality of service is of paramount importance for the operators and the users of the service;
- c) that it is necessary to provide to the operators and to the regulators the necessary tools to investigate harmful interference;
- d) that the techniques used in these networks require acceptable methods of direction finding;
- e) that the interference complaints dealing with the modern cellular networks are often difficult to resolve;
- f) that the systems using time division multiple access (TDMA) and code division multiple access (CDMA) technologies form a significant portion of today's radiotelephony services in the world;
- g) that the equipment with the capability of performing direction finding on digital signals is now commercially available,

recommends

- 1** that capacities of direction finding of TDMA and CDMA signals using synchronization should be implemented in the fixed and mobile monitoring stations;
- 2** that the process of direction finding should use the principles similar to those presented in Annex 1 and methods explained in Annex 2 and in Annex 3.

ANNEX 1

**Processing of radio direction finding and location
on TDMA and CDMA signals**

Concerning the radio direction finding of TDMA and CDMA signals, it is recommended to try to get a preliminary identification of the signal before or during the process of direction finding, in order to be able to use the applicable methods for radio direction finding of TDMA and CDMA signals. With this intention, an association between the techniques of radio direction finding and the techniques of preliminary identification are interesting. Indeed, the cooperative techniques are more effective in terms of precision and multisource context than the non cooperative methods.

- A radio direction finder able to process the discontinuous signals such as TDMA, CDMA or time division duplex signals should thus allow the successive application of several methods intended to improve the accuracy of radio direction finding in blind context and real time in a first phase, according to the regular methods recommended in Annex 2.
- Single channel or preferably multichannel recording of the signal being the subject of radio direction finding.
- Preliminary identification of the signal by intercorrelation with test signals, to be carried out in real time or slightly differed time.

And

- If the preliminary identification process fails radio direction finding in blind context as described in Annex 2 (synchronization and eventually high resolution methods) which can be carried out in real time or in differed time (with a multichannel recorded signal), to obtain a better angular precision, while increasing capacities of discrimination of the sources in medium difficult environments (multipath, multisource).
- If the preliminary identification process is a success, radio direction finding in a cooperative context as described in Annex 3, can be carried out in real or differed time (with a multichannel recorded signal) to obtain a better angular precision, while increasing very significantly capacities of discrimination of the sources in adverse environments (multipath, high density multisource context).

ANNEX 2

Blind context for radio direction finding with TDMA signals

If the waveform is not identified or can not be identified by the preliminary identification process and if no information is available on a possible discriminating parameter within the signal (blind context environment) then it is recommended to apply the following methods of direction finding:

All these methods could be improved by directional antennas, preliminary recognition of their technical parameters (carrier, bandwidth, type of modulation, slot duration, etc.) when they are available and multiples measurement (for triangulation processing, homing processing etc.).

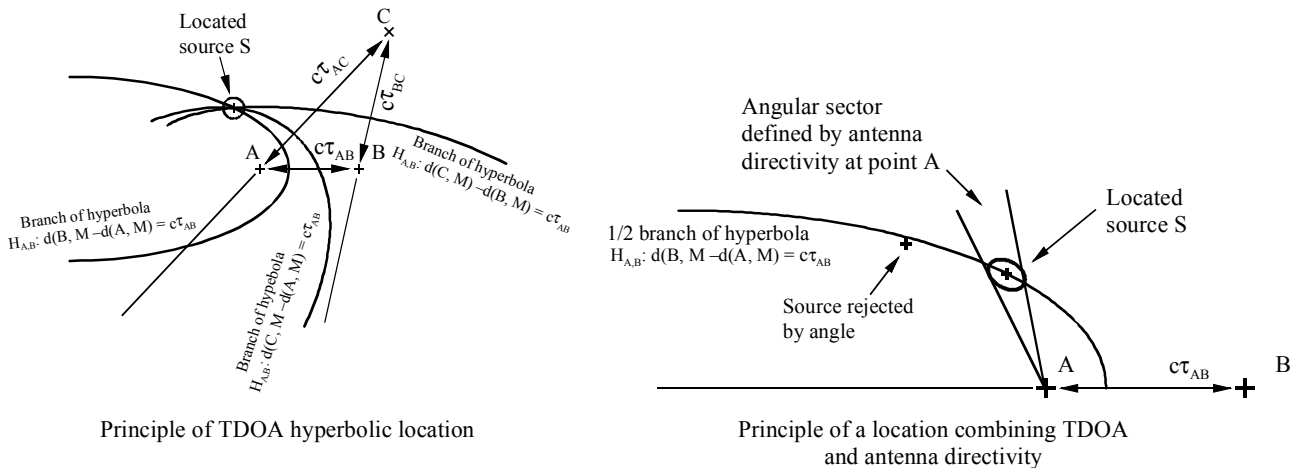
- Traditional or correlative interferometry (sequential or parallel with multichannels) may be coupled to a signal synchronization by detection of energy. The principle of interferometry is the calculation of phase delay between the signals obtained on several sensors, and the comparison between the result and a table of calibration to obtain the direction of the source. Synchronizing the direction finding trigger with the time of arrival of the time slots determined by a calculation of the energy of the signal present has many advantages:
 - the direction finder is triggered during the effective duration of a time slot;
 - except in the event of interference between time slots (see afterwards), the direction finder operates on a signal coming from a single source.

The advantage of a parallel rather than sequential direction finder is related to the fact that the switching of antenna is not necessary. Thus the longer integration of the signal provides an additional gain and precision of approximately 7 dB for a measurement over the duration of a time slot.

- Regular high resolution methods such as the MUSIC algorithm for performing more complex receiving situations involve interference or adverse propagation conditions, etc. The principle of such a technique is based on the calculation and the reduction of the autocorrelation matrix of the signal received at each sensor of the antenna array. These methods require more computing power and delay than correlative interferometry. The advantages of such techniques are the following:
 - Their accuracy is better than the correlative interferometry.
 - They perform direction finding even in multi-emission or interference situations (low to medium interference density may be performed. This depends on the number of antenna elements).
 - Direction finding is performed even on multipath propagation conditions.
 - In addition, as for correlative interferometry, it is possible to synchronize the direction finding trigger with the time of arrival of the time slots of TDMA signals with the numerous advantages pointed out in the previous paragraph.
- The time difference of arrival (TDOA) technique is based on intercorrelation of the digital signals received on a set of sufficiently distant and synchronous sensors to allow the hyperbolic location of the source. The basic principle of such method in a 2D geometry is the following: In a single transmitter situation, by considering a couple of synchronous antennas (A, B) at a convenient distance, the intercorrelation processing of the signal received at each antenna A and B provide a TDOA τ_{AB} , the corresponding location of the transmitter is given at an hyperbola branch H_{AB} defined by the location of the antennas A and B, and by the TDOA τ_{AB} . By considering another couple of distant synchronous antennas (A, C) and the same the intercorrelation processing of the signal received at each antenna A and C, the corresponding location of the transmitter is given at an hyperbola branch H_{AC} defined as before by the location of antennas A and C, and by the TDOA τ_{AC} . Thus, the location of the transmitter is given by the intersection of the hyperbola branch H_{AB} and H_{AC} . Note that even in a single transmitter situation, geometrical ambiguities may occur and precision depend highly on the geometrical configuration. This may be solved by using directive antennas or additional direction finding process.

In a multisource context, the TDOA technique can be improved by the use of directional aerials, making it possible to limit the angular scanned field and the risks of ambiguity caused by multiple transmitters and the risk of false association of TDOAs related to different transmitters. In addition, directional aerials can limit the number for synchronous measurements to only two antennas. The hyperbolic location can then be used to refine the precision obtained starting from angular measurements or to resolve ambiguities.

FIGURE 1
Blind TDOA location



1598-01

The TDOA technique is also possible as a blind method vis-à-vis the spread spectrum waveforms (CDMA). It is also possible in cooperative context, but is of lesser interest than the techniques recommended below, within this specific framework. Blind or cooperative TDOA techniques are considered for deployment using cellular network infrastructure for emergency call location.

ANNEX 3

Cooperative context on TDMA and short or known code CDMA waveforms

In this case, which applies to signals using TDMA or CDMA with short codes, the waveform has standardized parameters included in service and traffic channels and emitted continuously or at intervals known sequences present inside TDMA slots, PILOT codes or synchronization codes in the case of CDMA protocols, etc. In the following, such signals will be called known signals and noted:

- Sequential or parallel traditional or correlative interferometry is coupled to a synchronization on the signal by intercorrelation. The principle of interferometry is the calculation of the phase delay between the signals obtained on several sensors, and the comparison between the result and a table of calibration to obtain the direction of the source. The fact of synchronizing the direction finding trigger with the time of arrival of the time slots determined by a calculation of intercorrelation of the signal with a sequence of reference included in the signal has an increased advantage compared to the blind techniques. The additional interest lies in the improvement of the process of synchronization, made more sensitive and more reliable thanks to the exploitation of the known sequences of the signal.

This technique is sufficient in many practical cases of low density environment.

- Parallel cooperating interferometry based on the determination of a reference of phase on each sensor by total or partial intercorrelation of the signal received with the discriminating signal (a partial only intercorrelation can be considered in the case of CDMA protocols using long codes (IS 95, Globalstar)). The set of phase delays is compared with a table of calibration.

This technique presents multiple advantages:

- it makes it possible to benefit from a significant gain in detection due to the multichannel intercorrelation, which largely improves the sensitivity of the radio direction finder and its performances in multisource context;
 - the resolution obtained on the raw measurement of the phase is about $cT_S/2$ to cT_S , T_S representing the duration of a symbol (or of a chip in the case of a synchronization on codes of CDMA protocols). Accuracy is even better with comfortable $C/(N+I)$ ratios. This intrinsically precise raw measurement makes it possible to improve at the same time convergence of the location (i.e. to limit the number of bearings to be taken), its precision and its reliability;
 - it makes it possible to separate the sources in the same band when they use sequences, words or different codes of synchronization; it thus makes it possible to work in a multi-mission context when the sources show different discriminating characteristics or are separated by a time delay longer than the duration of few symbols;
 - it makes it possible to carry out countings, to measure percentages of occupancy (occupancy of times slots in the case of TDMA protocols, occupancy of the codes in the case of CDMA protocols), and to associate location and technical measurements.
- Multichannel adaptive techniques based on the exploitation of the matrices of autocorrelation and intercorrelation of the signal with the sequences of reference contained in it. Concerning these techniques, there are two possible approaches:
 - *Multichannel synchronization and generic high resolution direction finding method* (MUSIC, ESPRIT and derived methods, etc.), that were mentioned previously, and that improve the performances of the direction finder by interferometry in multisource context or when propagation difficulties occur (multipaths).
 - *Multichannel synchronization and separation of sources by adaptive techniques and dedicated high resolution method for direction finding:*
 - The adaptive filtering methods for synchronization uses adaptive space-time filters and optimizes the detection and the reception of the TDMA or CDMA sources. They perform the demodulation of the signals emitted while rejecting the interfering signals. They in particular make it possible to solve situations of co-channel and adjacent channel interferences in the cellular networks or in networks using multiple sources, location of the sources being obtained by means of their identification (for example in the case of a GSM network, one demodulates and one decodes the beacon channels to extract the data of identification from the base stations, such as BSIC, CI, and LAC in GSM networks, which provide their

positions through consultation of the operator, and to extract the synchronization data – frame number – which make it possible to synchronize networked radio direction finders).

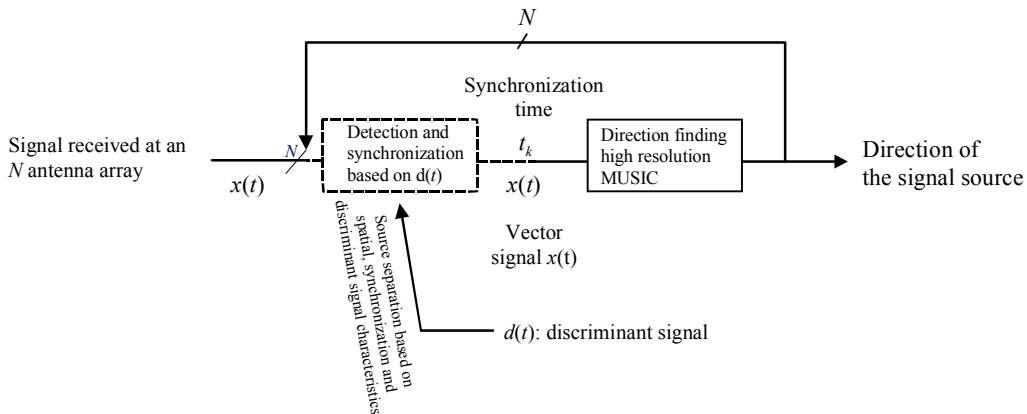
- In addition, multichannel methods make possible the use of very accurate high-resolution direction finding processing that are dedicated for TDMA and CDMA wave forms, even under highly disturbed conditions (strong interferences), as shown in Figs. 2, 3 and 4.

The adaptive techniques thus supplement very effectively the solutions suggested previously for very difficult situations: propagation in dense urban environment, intensive re-use of the frequencies in the 2G and 3G cellular networks, high incidence signals, etc., especially when multiple close reflectors disturb the wavefront and prevent accurate angular location (typical of urban area conditions).

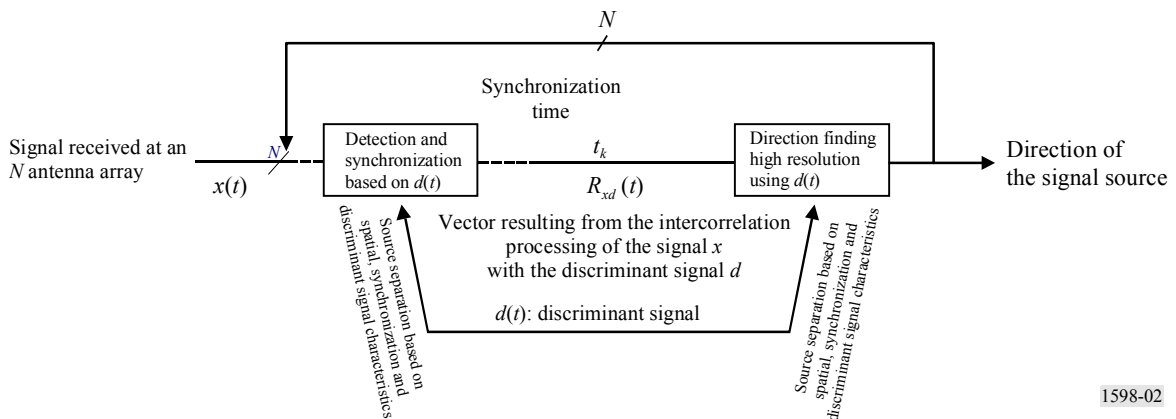
The above-mentioned adaptive techniques are well adapted to complex situations and post processing in slightly differed times.

FIGURE 2
**High resolution methods for direction finding in cooperative context;
 example of practical implementation**

Using a generic high resolution method for direction finding with or without a first synchronization step based on the discriminant signal



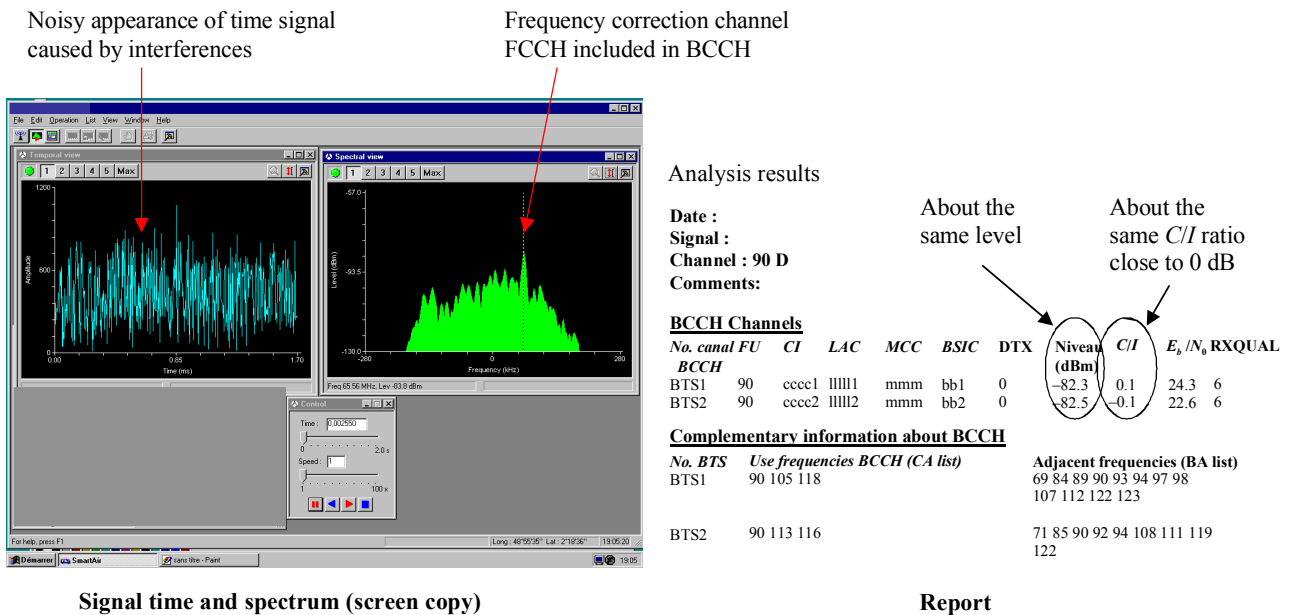
Using a specific high resolution method for direction finding that is dedicated to the discriminant signal d



Figs. 2, 3 and 4 show illustrations and results of these methods:

- Figure 2 shows two possible practical implementations of multichannel synchronization and direction-finding functions inside spectrum monitoring and measurement systems;
- Figure 3 shows the results of the adaptive filtering method in two real field interfering situations inside GSM networks;
- Figure 4 shows an example of source separation and direction finding results in interfering situations involving GSM beacon frequencies. As above, these results were obtained from a real case experiment inside a GSM network.

FIGURE 3
Example of use of adaptive filters source synchronization, identification and location under adverse receiving conditions inside GSM networks



Conclusion: BTS1 and BTS2 have about the same BCCH level. Their BCCHs interfere strongly with each other. A simple interfering situation involving signalling channels (BCCH at beacon frequencies).

Note 1 - Identification parameters of networks and cells (MCC, MNC, CI, LAC, etc.) are decoded but their real values are masked for confidentiality.

FIGURE 4

**High resolution methods for direction finding;
example of result inside a GSM network**

Example of direction finding results provided by a high resolution method and a synchronization step based on a discriminant GSM signal

Direction finding of 2 GSM base stations sharing the same frequency is achieved by using a five antenna array and a recorded signal during 2 s. The discriminant signal used here is the SCH burst that is present at GSM beacon frequencies

