A DOPPLER ESTIMATION FOR UMTS-FDD BASED ON CHANNEL POWER STATISTICS

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Abstract -- A Doppler estimation based on a statistical analysis of the channel power variations is proposed for the Frequency Division Duplex (FDD) mode of next Universal Mobile Telecommunication Systems (UMTS). Its implementation is considered in both cases of constant power and closed-loop power controlled transmissions. Performance is analyzed in terms of velocity estimation error under various conditions of speed, estimation delay and Signal-to-Interference plus Noise Ratio (SINR). The influence of a SINR-based power channel estimation is also taken into account. Results show the reliability of this Doppler estimation technique that yields estimates with less than 15km/h error in a velocity range from 0km/h to 100km/h. Results also present the impact of the closed-loop power control on the Doppler estimation reliability.

I. INTRODUCTION

Next generation wireless cellular systems such as Universal Mobile Telecommunication Systems (UMTS) will allow communications with a mobile station velocity up to 500 km/h. The time variations of such a propagation channel can be related to the Doppler effect that arises, leading to performance degradations of different functions of the transmission chain.

The knowledge of this Doppler effect can help to optimize the mobile transmission system at the physical level as well as at higher levels of the protocol stack. For example, it may help to optimize the interleaving lengths in order to reduce the reception delays [1]. The related velocity estimation can also greatly influence the cell layer assignment strategy: low speed mobile stations would be assigned to pico-cells, medium speed mobile stations to micro-cells and high speed mobile stations to macro-cells [2]. The location services that rely on the emission of control information at a rate proportional to the mobile velocity also require a velocity estimation [3]. However, current mobile communication systems do not usually estimate the Doppler effect but try to take into account its effect through rapid channel estimation and carrier synchronization devices.

This paper proposes a robust Doppler estimation technique (similar to that proposed in [4]) based on the analysis of the channel power statistics and adapted to Wideband Code Division Multiple Access (W-CDMA) transmission systems. The paper is organized as follows. In section II, the transmission power model is described in case of constant emitted power and in case of closed-loop power control. In section III, the Doppler estimation algorithm is presented with its application in both cases of transmission. Simulation results are presented in section IV for the UMTS-FDD mode. The intrinsic performance of the algorithm, the influence of the noise and the impact of a standard closed-loop power control algorithm are presented. Finally, conclusion is proposed in section V.

II. TRANSMISSION POWER MODEL

For clarity reasons, we will consider the simplified power scheme depicted in Fig. 1 where each power value is represented in the decibel domain at sampling time *n*: *T(n)* is the power value of the emitted sample, *C(n)* is the power response of the channel and *R(n)* is the power value of the received sample.

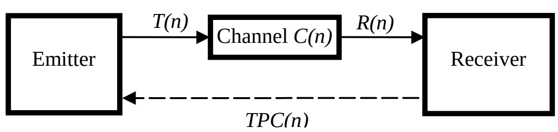

Fig. 1: Simplified power model of the transmission.

Thus,

$$R(n) = C(n) + T(n) \quad (1)$$

For UMTS FDD, the sampling period corresponds to a slot duration of 0.625 ms.

As multipath propagation is considered, the channel response results from the combination of L different paths coming from different directions. The i-th (i =1,..,L) path is assumed to have a Rayleigh distributed amplitude, which can be modeled as the product of a normalized multiplicative distortion $f_i(t)$, and an amplitude a_i, *i.e.*

$$f_i(t) = a_i \bullet f_d(t) \quad (2)$$

where $F_d(f)$ is

$$F_d(f) = \frac{1}{\sqrt{1-\left(\frac{f}{f_d}\right)^2}} \quad with \quad f_d = \frac{f_0 \bullet v_d}{c} \quad (3)$$

where f_0 is the transmitting frequency, v_d is the mobile velocity and c is the celerity of the light.

The *TPC(n)* signal is only used if a closed-loop power control of the received power *R(n)* is included in the transmission scheme, as it is for UMTS-FDD systems [5]. In such a case, the receiver sends a power control command *TPC(n)* that generally results from the comparison between *R(n)* and a required power level R_{req}. Then, according to *TPC(n)*, *T(n)* takes values so that *R(n)* is kept as constant as possible around R_{req}, in order to avoid power variations due to *C(n)* and to ensure a quasi-constant quality of service. Then, if the errors affecting the transmission of the power control command are neglected, the emitted power is directly controlled by the *TCP(n)*, *i.e.*,

$$T(n) = T(n-1) + TPC(n-x) \quad (4)$$

where x represents the delay (normalized to the power sampling time) of the power control loop. This delay integrates all the delay contributions of the transmission chain, coming from the propagation channel, the computations or the synchronization processes.

III. DOPPLER ESTIMATION MODEL

Considering a channel with Rayleigh distributed amplitude corresponding to a time-varying single-path propagation, it was recently shown [6] that the expression of the decibel channel power autocovariance function derives from the Bessel function of the first kind of order zero,

$$Cov_C[i](n) = \gamma^2 J_0^2\left[\omega_d(n) i T_b\right] \bullet \Phi\left\{J_0^2\left[\omega_d(n) i T_b\right], 2, 1\right\} \quad (5)$$

where:

$Cov_C[i](n) = E[C(n)C(n+i)] - E[C(n)]^2$,

E is the expectation,

$1/T_b$ is the rate of channel power samples,

i is the delay (normalized to the power sampling time T_b) between two channel power samples,

$\gamma = 10/ln(10)$,

$\omega_d = 2\pi . f_d$ is the Doppler shift,

$J_0(x)$ is the Bessel function of the first kind of order zero,

and $$z \bullet \Phi\{z,2,1\} = \sum_{n=1}^{+\infty} \frac{z^n}{n^2} \quad (6)$$

From (6), it follows that z.Φ(z,2,1) is a monotonously increasing function. Thus, maximum (resp. minimum) values of the autocovariance $Cov_C[i](n)$ are reached when $J_0(x)$ is maximum (resp. minimum). Moreover, the location of $J_0(x)$ extrema is known from the mathematical literature [7]. For instance, the location of the lowest positive zero x_0 of the $J_0(x)$ derivative function is x_0=3.8317. Then, given T_b, for each Doppler shift ω_d (or each mobile velocity v_d) corresponds a delay i_0 that makes the autocovariance function $Cov_C[i](n)$ reach its first extremum value.

In other words, an estimation of this delay i_0 directly gives an estimation ω'_d of the Doppler shift ω_d and an estimation v'_d of the mobile velocity v_d, with

$$\omega'_d = \frac{3.8317}{T_b i_0} \quad (7)$$

Thus, the Doppler can be estimated from the knowledge of the autocovariance function of the channel power.

A. *Doppler estimation algorithm*

According to (7), the Doppler estimation greatly depends on the reliability of i_0 estimation. In order to face with the influence of noise, interference and estimation mismatches, a filter is introduced prior to estimation.

Assuming the knowledge of the channel power samples *C(n)*, the Doppler estimation consists in the determination of the location of the lowest positive zero i_0 of a filtered derivative function of $Cov_C[i](n)$ with respect to i.

In a first step, the derivative function of $Cov_C[i](n)$ is estimated over a slide of N channel power samples for a range $i \in [0, i_{max}]$:

$$\frac{\partial}{\partial i}\left(Cov_C[i]\right)(n) \approx \frac{1}{N}\sum_{j=n}^{n+N-1} C(j) \bullet \left(C(j+i+1) - C(j+i)\right) \quad (8)$$

In a second step, a recursive filtering is applied to the slide of i_{max}+1 derivative values obtained from (8) in order to avoid an excessive estimation noise.

In a third step, the two first consecutive delays, for which the sign of the filtered derivative function of the channel power autocovariance changes, are used to deliver i_0 by linear interpolation.

Finally, the Doppler shift estimate ω'_d and the mobile velocity estimate v'_d are obtained from i_0 thank to a look-up table that takes into account the transmission parameters (T_b, f_0) and the filter.

As N consecutive channel power samples are used to yield one Doppler estimate, an average delay $D=N.T_b/2$ is introduced in the estimation process.

Here, it is assumed that the channel power autocovariance resulting from Doppler-shifted paths arriving at the same time is similar to the channel power autocovariance resulting from Doppler-shifted paths arriving at different times.

B. Application to transmission with constant emitted power

Assuming a transmission with constant emitted power $T(n) = T_0$ over a restricted period of time, $R(n)$ can be used to estimate the Doppler shift since $R(n)$ variations directly correspond to $C(n)$ variations. So,

$$\frac{\partial}{\partial i}\left(Cov_C[i]\right)(n) = \frac{\partial}{\partial i}\left(Cov_R[i]\right)(n) \quad (9)$$

Thus, an estimation of the Doppler shift is possible at the receiver side.

C. Application to transmission with closed-loop power control algorithm

In case of a transmission with closed-loop power control as it is for UMTS, both the emitter and the receiver can apply the Doppler estimation algorithm described in III.A. Indeed, according to (1) and (4), an estimation $C'(n)$ of the channel power $C(n)$ can be performed at the receiver side as follows:

$$C'(n) = R(n) - \tfrac{z^{-x}}{1-z^{-1}} TPC(n) \quad (10)$$

Then, the Doppler estimation algorithm can be processed over a slide of N samples $C'(n)$:

$$\frac{\partial}{\partial i}\left(Cov_{C'}[i]\right)(n) \approx \frac{\partial}{\partial i}\left(Cov_C[i]\right)(n) \quad (11)$$

Note that $C'(n) = C(n)$ if no error affects the transmission of the $TPC(n)$ commands and if the power control rule used by the emitter is perfectly known at the receiver side. Besides, the reliability of relation (11) does not depend on the power control efficiency.

At the emitter side, if we denote $\varepsilon(n)$ as the power control mismatch, that is the power difference between $R(n)$ and R_{req}, it can be shown that:

$$\begin{aligned} Cov_T[i](n) &= Cov_C[i](n) + Cov_\varepsilon[i](n) \\ &- E[C(n)\varepsilon(n-i)] - E[\varepsilon(n)C(n-i)] \\ &+ 2E[\varepsilon(n)]E[C(n)] \end{aligned} \quad (12)$$

Assuming $C(n)$ and $\varepsilon(n)$ as statically independent processes, we get:

$$Cov_T[i](n) = Cov_C[i](n) + Cov_\varepsilon[i](n) \quad (13)$$

Thus, the autocovariance of the emitted power is equal to the autocovariance sum of the channel power and the power control mismatch.

Finally, assuming the efficiency of the power control, which leads to consider a power control mismatch $\varepsilon(n)$ close to zero, it follows:

$$\frac{\partial}{\partial i}\left(Cov_T[i]\right)(n) \approx \frac{\partial}{\partial i}\left(Cov_C[i]\right)(n) \quad (14)$$

Then, also at the emitter side, the Doppler estimation algorithm can be processed with $T(n)$ samples.

IV. Simulation results in a UMTS environment

In the following performance analysis, the performance criterion is the error standard deviation of the mobile velocity estimation denoted σ_d where

$$\sigma_d = \sqrt{E\left[\left(v'_d - v_d\right)^2\right]} \qquad \text{(in km/h)} \quad (15)$$

Simulation results are presented with UMTS-FDD parameters [4]. The carrier frequency is 2 GHz, the sampling frequency is 4 MHz. As channel power model, we consider the contribution of 4 paths with Rayleigh distributed amplitude and relative averaged power equal to -13 dB, -12 dB, -4 dB and -3 dB. Closed-loop power control relies on $TPC(n)$ commands that are generated every slot (T_b=0.625 ms) and are taken into account after a delay $x=2$ slots by the emitter. Orthogonal Walsh spreading sequences with 256 processing gain are considered. The look-up table granularity of the velocity estimator is 2.5 km/h from 0 to 100 km/h.

Simulation results focus on the intrinsic performance of the estimator and on the influence of a SINR-based channel power estimation with constant emitted power. Then, the impact of a standard closed-loop power control through approximations (11) and (14) is analyzed.

A. Intrinsic performance

In order to evaluate the intrinsic performance of the velocity estimation technique, we first consider the case of non closed-loop power control transmission systems without noise and interference where the velocity estimation can be processed at the receiver

side with perfect knowledge of the channel power variations according to (9).
In Fig.2 is plotted the error standard deviation of the mobile velocity estimation versus the actual velocity v_d. Each point results from a processing of the velocity estimation during 2 min of transmission. The curves differ by the estimation delay D, from 62.5 ms up to 1 s.

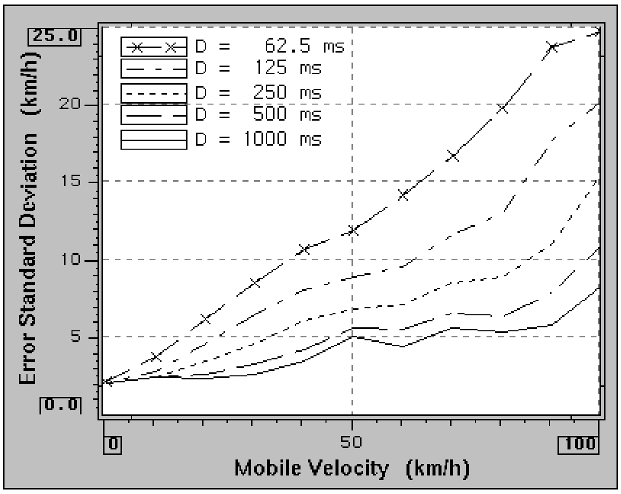

Fig. 2: Influence of the mobile velocity on the error standard deviation for different estimation delays.
(perfect channel gain estimation)

Whatever the estimation delay D, the variance slightly increases with the actual mobile velocity. At low speed (pedestrian case), the error standard deviation is never higher than 5 km/h and is almost independent of the estimation delay. For medium and high speeds, the error standard deviation is larger when short estimation delays are considered. If D is larger or equal to 0.25 s, the error standard deviation is never higher than 15 km/h. As we can see, a trade-off between the minimization of the estimation delay and the minimization of the error standard deviation has to be found.
Since the Doppler estimation has to cover a wide range of velocity and acceleration, choosing 0.25 s as estimation delay seems to be a reasonable trade-off since no significant velocity variations will happen during such a short period.

B. Influence of SINR estimation

Usually, the channel power variations due to MS mobility is deduced from SINR variations, which estimation is often required in order to adapt the parameters of some correction devices such as power controller or channel decoder. Therefore, the estimation of the channel power variations based on SINR estimation is taken into account in what follows. For UMTS-FDD systems, we will consider SINR estimations processed every 0.625 ms. A multi-user transmission is considered by modeling the interference of other users as a white gaussian process. The SINR estimation is then carried out in two steps: a signal projection on the Walsh sequence of the desired user yields the signal power estimation; a signal projection on the other Walsh sequences yields the interference plus noise power estimation.

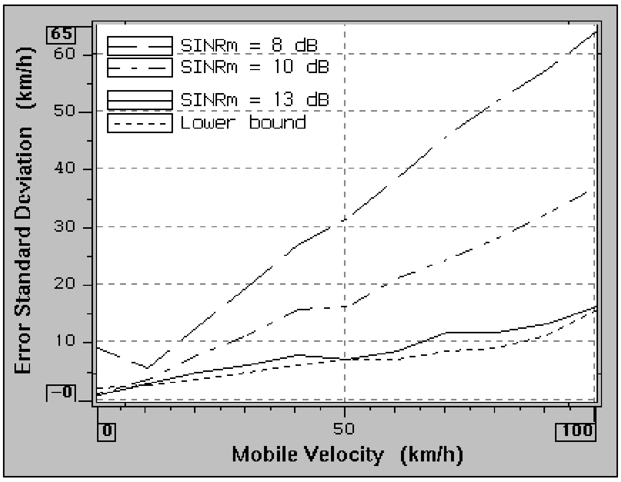

Fig. 3: Influence of the mobile velocity on the error standard deviation for different SINR$_m$ levels.
(SINR based channel power estimation, D = 0.25s)

Fig.3 represents the influence of the SINR-based channel power estimation on the velocity estimation performance. Results are plotted in terms of error standard deviation versus actual velocity v_d for different values of mean SINR denoted $SINR_m$. According to the results plotted in Fig.2, estimation delay D = 0.25 s is considered.
As a lower bound of the error standard deviation, we consider the case with an exact knowledge of the channel power as depicted in Fig.2 for D = 0.25 s. Simulation results confirm the good performance of the estimation algorithm even in case of interference, noise and some channel power estimation mismatches. Indeed, comparing to the lower bound, even for $SINR_m$ = 10 dB, the increase of error standard deviation is never larger than 20 km/h. For $SINR_m$ = 13 dB, the increase of error standard deviation is reduced to at most 4 km/h. Increasing the SINR does not significantly improve the performance.

C. Influence of closed-loop power control

In case of a closed-loop power controlled transmission, the performance of the velocity estimation depends on the reliability of approximations (11) and (14), which depends on the efficiency of the power control algorithm. Consider the case of an uplink power control transmission where the emitter of Fig.1 is the Mobile Station (MS) while the receiver is the Base

Station (BS). We consider the standard closed-loop power control algorithm:

$$TPC(n) = -1dB \qquad if \qquad R(n) - R_{req} \geq 0$$
$$TPC(n) = +1dB \qquad if \qquad R(n) - R_{req} < 0$$

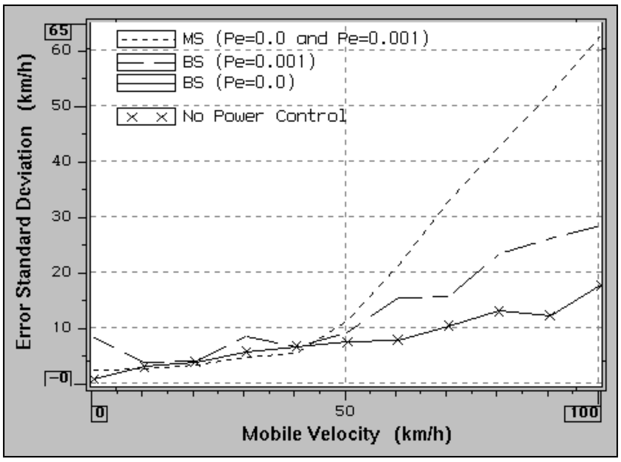

Fig. 4: Influence on the error standard deviation of closed-loop power control with TPC transmission errors ($SINR_m$=13dB,D=0.25s,SINR-based channel power estimation).

Fig.4 depicts the influence of the standard closed-loop power control algorithm on the performance of the velocity estimation at $SINR_m = 13$ dB for an estimation delay $D = 0.25$ s. The cases of a TPC transmission with or without error are considered where the error probability on the TPC transmission is denoted *Pe*.The velocity estimation is based on the SINR-based channel power estimation, which influences are plotted above on Fig.3. The velocity is estimated at the receiver side according to relation (11) and at the emitter side according to relation (14). As a lower bound of σ_d, we consider the case with no power control depicted in Fig.3 for $SINR_m = 13$ dB.

If no error affects the transmission of TPC commands (Pe=0.0), the velocity estimation at BS achieves the lower bound performance. This results from the a priori knowledge at the BS of the way the TPC command is taken into account at the MS. In comparison, at the MS, the performance of the velocity estimation for low speeds [0,40km/h] is very close to that obtained with constant emitted power which confirms the validity of relation (14). However, for higher mobile velocities, this relation is no more valid and performance drastically degrades up to more than 60 km/h of error standard deviation at 100 km/h. This bad performance results from the limitations of the standard closed-loop power control algorithm to keep a constant SINR level with rapid channel changes.

If some errors affect the transmission of *TPC(n)* commands ($Pe=10^{-3}$), the degradation is sensitive at the BS since approximation (11) relies on the assumption of a perfect knowledge of the power update rule at the BS, which is no more valid. In comparison, such an assumption is not required at the MS side, and no degradation occurs due to the transmission errors.

Finally, we can expect that a predictive closed-loop power control algorithm will improve the performance of the Doppler estimation, namely at the emitter side. Such an improvement is under study.

V. Conclusions

This paper proposes a simple and effective method to estimate the Doppler shift and the relative mobile velocity observed during the transmission between one fixed and one mobile station, or two mobile stations. This simple method can be applied to any communication systems, with or without power control. Simulation results in a UMTS-FDD environment show that the mobile velocity can be estimated with a very good precision (15 km/h at 100 km/h) and low estimation delay (0.25 s), even when the channel power estimation is based on actual SINR estimation at low SINR. Simulation results also show the impact of the closed-loop power control algorithm on the performance.

VI. References

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