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Title: Pilot pattern for CPICH

Document for: Discussion

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1. Introduction

In the last meeting in New York, a proposal to change pilot pattern for CPICH was presented [1]. In the document, following two concerns were raised as problems with current pilot pattern.

- Complexity of DFT AFC algorithm proposed in [2].
- Inadequate frequency acquisition range with current pilot pattern, stating that its capability is limited to +/-3.75kHz if conventional differential frequency detection were used.

In addition, it was claimed that the frequency acquisition range using pilot pattern #3 described in [1] is +/-7.5kHz.

This document is to focus on frequency acquisition issue raised in R1-99g62, and to show that the current pilot pattern does have its frequency acquisition capability up to +/-7.5kHz. Furthermore, our analysis show that using differential detection method shown in [1] only has acquisition range of +/-3.75kHz.

2. Differential Detection using current pilot pattern

The differential frequency offset detection can be applied on current pilot pattern to obtain the acquisition range of +/-7.5kHz. The concept of the method is shown below.

Ant#1	A	A	A	A	A	A	A	A	A	A
Ant#2	A	-A	-A	A	A	-A	-A	A	A	-A

Detection Pair. Detection Pair. Detection pair. Detection Pair.

Since each symbol in “frequency offset detection pair” is obtained per 256 chip period, the detection range is +/-7.5kHz.

3. The analysis for acquisition rage using proposal given in [1]

In [1], the following pilot pattern for CPICH is proposed.

Ant#1	A	A	A	A	A	A	A	A	A	A
Ant#2	A	-A	A	-A	A	-A	A	-A	A	-A

Detection Pair

The following is the analysis made to show that the frequency acquisition range is limited to +/-3.75kHz using above pilot pattern with differential detection method shown in [1].

The following analysis is made based on assumption and notation given below:

Channel Characteristics from Ant#1: a_1 (Complex number)

Channel Characteristics from Ant#2: a_2 (Complex number)

$\Delta w = 2p\Delta f$ (Δf : frequency offset)

q : absolute phase offset between Tx and Rx

Define the transmitted signal from each antenna of base station as follows.

$$S_1(t) = x_1(t)\cos w_c t - y_1(t)\sin w_c t$$

$$S_2(t) = x_2(t)\cos w_c t - y_2(t)\sin w_c t$$

With presence of frequency offset, the observed signal seen by a receiver can be expressed as follows,

$$I(t) = \tilde{x}(t)\cos(\Delta wt + q) + \tilde{y}(t)\sin(\Delta wt + q)$$

$$Q(t) = \tilde{y}(t)\cos(\Delta wt + q) - \tilde{x}(t)\sin(\Delta wt + q)$$

where

$$\tilde{x}(t) = \tilde{x}_1(t) + \tilde{x}_2(t)$$

$$\tilde{y}(t) = \tilde{y}_1(t) + \tilde{y}_2(t)$$

and

$$\tilde{x}_1 + j\tilde{y}_1 = a_1(x_1 + jy_1) \qquad \text{..............(A)}$$

$$\tilde{x}_2 + j\tilde{y}_2 = a_2(x_2 + jy_2)$$

And the complex envelope of the received signal can be expressed as,

$$U(t) = I(t) + jQ(t)$$

$$= (\tilde{x}(t) + j\tilde{y}(t))e^{-j(\Delta wt + q)}$$

$$= [(\tilde{x}_1(t) + j\tilde{y}_1(t)) + (\tilde{x}_2(t) + j\tilde{y}_2(t))]e^{-j(\Delta wt + q)}$$

With the substitution of equation (A),

$$U(t)=[a_1((x_1(t)+jy_1(t))+a_2(x_2(t)+jy_2(t))]e^{-j(\Delta wt+q)}$$
$$=[a_1Tx_1(t)+a_2Tx_2(t)]e^{-j(\Delta wt+q)}$$
$$=[a_1D_1(t)C(t)+a_2D_2(t)C(t)]e^{-j(\Delta wt+q)}$$
$$=[a_1D_1(t)+a_2D_2(t)]C(t)e^{-j(\Delta wt+q)}$$

After the de-spreading operation, signal seen by a receiver is,

$$Z(kT)=\int_{(k-1)T}^{kT}U(t)C^*(t)dt$$
$$=\int_{(k-1)T}^{kT}[a_1D_1(t)+a_2D_2(t)]C(t)e^{-j(\Delta wt+q)}C^*(t)dt$$

where T is in 256 PN chip unit.

With assumptions $C(t)C^*(t)=|C(t)|^2=1$, a_1,a_2 constant over de-spreading period, and since the pilot pattern $D_1(t)=D_2(t)=A$ for $(k-1)T\le t\le kT$, the above equation can be transformed as

$$Z(kT)=\int_{(k-1)T}^{kT}[a_1D_1(t)+a_2D_2(t)]e^{-j(\Delta wt+q)}dt$$
$$=a_1\int_{(k-1)T}^{kT}D_1(t)e^{-j(\Delta wt+q)}dt+a_2\int_{(k-1)T}^{kT}D_2(t)e^{-j(\Delta wt+q)}dt$$
$$=a_1\int_{(k-1)T}^{kT}Ae^{-j(\Delta wt+q)}dt+a_2\int_{(k-1)T}^{kT}Ae^{-j(\Delta wt+q)}dt$$
$$=(a_1+a_2)T\frac{\sin(\Delta wT/2)}{(\Delta wT/2)}e^{-j(\Delta w(K-\frac{1}{2})T+q)}\cdot A$$

On the other hand, for $kT\le t\le(k+1)T, D_1(t)=A, D_2(t)=-A$

$$Z((k+1)T)=a_1\int_{kT}^{(k+1)T}Ae^{-j(\Delta wt+q)}dt+a_2\int_{kT}^{(k+1)T}-Ae^{-j(\Delta wt+q)}dt$$
$$=(a_1-a_2)T\frac{\sin(\Delta wT/2)}{(\Delta wT/2)}e^{-j(\Delta w(K+\frac{1}{2})T+q)}\cdot A$$

And again, for $(k+1)T\le t\le(k+2)T, D_1(t)=D_2(t)=A$

$$Z((k+2)T)=a_1\int_{(k+1)T}^{(k+2)T}Ae^{-j(\Delta wt+q)}dt+a_2\int_{(k+1)T}^{(k+2)T}Ae^{-j(\Delta wt+q)}dt$$
$$=(a_1+a_2)T\frac{\sin(\Delta wT/2)}{(\Delta wT/2)}e^{-j(\Delta w(K+\frac{3}{2})T+q)}\cdot A$$

Now, if the de-spreading operation is performed over 512 chip, we obtain,

$$Z_1=a_1\int_{(k-1)T}^{(k+1)T}D_1(t)e^{-j(\Delta wt+q)}dt+a_2\int_{(k-1)T}^{(k+1)T}D_2(t)e^{-j(\Delta wt+q)}dt$$
$$=a_1\int_{(k-1)T}^{kT}D_1(t)e^{-j(\Delta wt+q)}dt+a_1\int_{kT}^{(k+1)T}D_1(t)e^{-j(\Delta wt+q)}dt+$$
$$a_2\int_{(k-1)T}^{kT}D_2(t)e^{-j(\Delta wt+q)}dt+a_2\int_{kT}^{(k+1)T}D_2(t)e^{-j(\Delta wt+q)}dt$$
$$=Z(kT)+Z((k+1)T)$$

$$
\begin{aligned}
Z_2 &= a_1\int_{kT}^{(k+2)T} D_1(t)e^{-j(\Delta wt+q)}dt + a_2\int_{kT}^{(k+2)T} D_2(t)e^{-j(\Delta wt+q)}dt \\
&= a_1\int_{kT}^{(k+1)T} D_1(t)e^{-j(\Delta wt+q)}dt + a_1\int_{(k+1)T}^{(k+2)T} D_1(t)e^{-j(\Delta wt+q)}dt + \\
&\quad a_2\int_{kT}^{(k+1)T} D_2(t)e^{-j(\Delta wt+q)}dt + a_2\int_{(k+1)T}^{(k+2)T} D_2(t)e^{-j(\Delta wt+q)}dt \\
&= Z((k+1)T) + Z((k+2)T)
\end{aligned}
$$

Now, the differential detection for phase offset can be carried,

$$
\begin{aligned}
Z_1^* \cdot Z_2 &= T\frac{\sin(\Delta wT/2)}{\Delta wT/2} e^{j(\Delta w(k-\frac{1}{2})T+q)} A^*[(a_1+a_2)^* + (a_1-a_2)^* e^{j\Delta wT}] \\
&\quad \times T\frac{\sin(\Delta wT/2)}{\Delta wT/2} e^{-j(\Delta w(k+\frac{1}{2})T+q)} A[(a_1-a_2)+(a_1+a_2)e^{-j\Delta wT}] \\
&= T^2\left(\frac{\sin(\Delta wT/2)}{\Delta wT/2}\right)^2 e^{-j\Delta wT}|A|^2[|a_1+a_2|^2 e^{-j\Delta wT} + |a_1-a_2|^2 e^{j\Delta wT} + 2(|a_1|^2-|a_2|^2)]
\end{aligned}
$$

For explanatory purpose, if we let $a_1 = a_2 = 1$,

$$
Z_1^* \cdot Z_2 = 4T^2\left(\frac{\sin(\Delta wT/2)}{\Delta wT/2}\right)^2 e^{-j\Delta w 2T}|A|^2
$$

The exponential term {-j $\Delta 2w$T} suggests that

$$
\begin{aligned}
&|2\Delta w\mathrm{T}| < p\ ,\ \Delta w = 2p\Delta f \\
&|\Delta f| < 1/4T \qquad (1/\mathrm{T} = 15kHz) \\
&|\Delta f| < 3.75kHz
\end{aligned}
$$

Therefore, the conclusion can be made to say that the upper limit for frequency acquisition is +/-3.75kHz using pilot pattern #3 proposed in [1].

4. Conclusion

With the analysis given above, we recommend WG1 to keep current pilot pattern for CPICH .

5. Reference

[1] Samsung, Nokia “Common Pilot Pattern”, TSGR1#8 (99)g62

[2] Ericsson, “Common Pilot Pattern”, TSGR1#7 (99)d17