High-Precision, Wide-Range Doppler Cancellation for LEO-Satellite Communications

Every wireless communication channel expects some degree of Carrier Frequency Offset (CFO) between the transmitter(Tx) and the Receiver (Rx) and modest level of CFOs are typically corrected as part of the receiver's digital signal processing at PHY level. However, when a high-degree of CFO exists it quickly becomes a difficult task for Rx to correct properly, resulting in drastically reduced channel capacity. A severe Doppler effect observed in typical wireless channel between LEO satellites and ground stations or airplanes often exacerbate CFO problem even further. When CFO problem is severe it also worsens the Sampling Frequency Offset (SFO) observed in Rx, which often becomes extra major hinderance when attempting to correct these offset errors (CFO & SFO) to improve channel capacity.

Our Patented **High-Precision Carrier Synchronization Technology (HPCST)** is a genuine breakthrough technology enabling a highly accurate instantaneous measurement of Carrier Frequency Offset (CFO) from a single frame of data, regardless of the modulation schemes deployed. Our algorithm accomplishes this task without having to decode data – therefore true blind synchronization method, yet delivers much more superior outcome compared to other conventional methods, which rely on embedded beacons. The superior performance of our method mainly comes from the fact that our method utilizes FULL transmitted energy in estimating the carrier frequency offset from the full frame of data. Below figure illustrates our methods in 3-D space.

(a) Carrier Frequency Offset (f_{os})
(b) Initial Phase Offset (ϕ_{os})

Our Algorithm effectively generates a 3-D map of a Sync Quality Function (SQF) from a single frame of data as shown here whose peak corresponds to the exact amount of f_{os} and ϕ_{os}

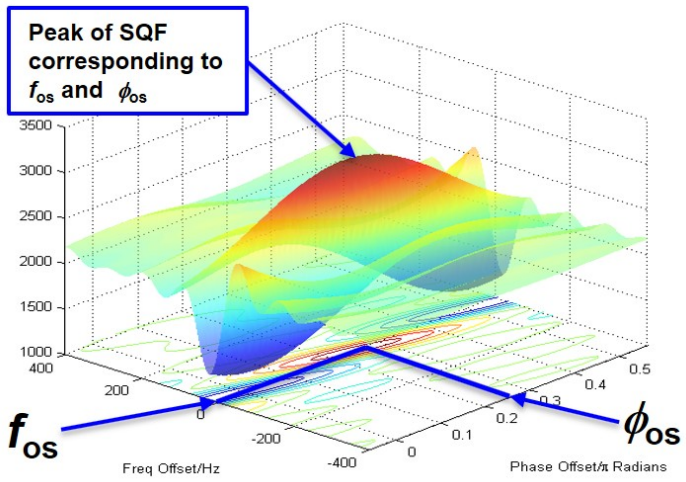

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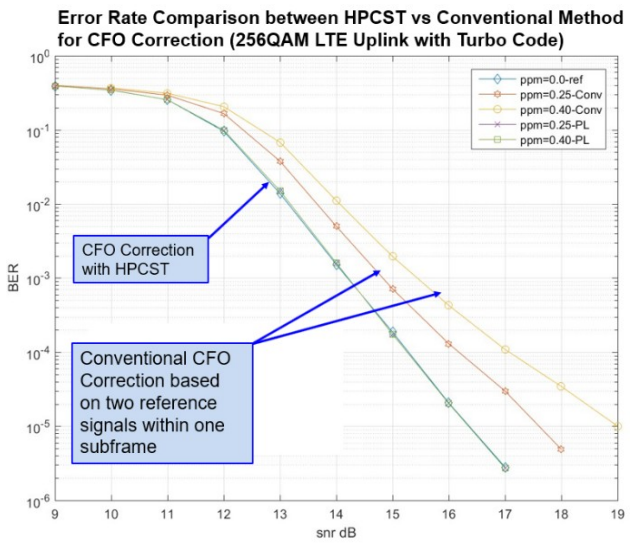
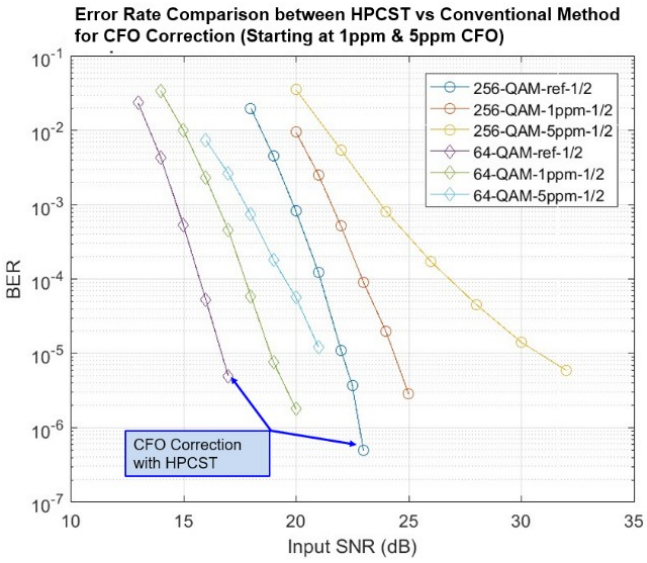
Figure 1. Graphical illustration of HPCST algorithm. Efficient peak search algorithm finds a precise amount of frequency offset and phase offset from a single frame of data in a true blind manner and yet delivers much more accurate outcome.

In order to accurately remove CFOs and SFOs caused by both Doppler Shift and hardware mismatch between Tx and Rx our patented approach also includes our method of combining both time-domain and frequency-domain PHY-level signal processing steps, which allows individualized sub-carrier-level corrections of OFDMA-like channels, which could be a bundle of multiple UE uplinks similar to LTE uplinks.

Shown below are some simulation results demonstrating the effectiveness of our methods for correcting high-degree of CFOs and SFOs expected of channels experiencing high level of CFO and Doppler shift.





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(a)

(b)

(c)

Figure 2. Simulation studies comparing the effectiveness of cancelling Carrier Frequency Offset (CFS) and Sampling Frequency Offset (SFO) between our High-Precision Carrier Synchronization Technology (HPCST) and other conventional method relying on embedded beacon pilot signals: (a) (b). Our simulation study shows HPCST method typically have little trouble removing CFO and SFO errors almost completely while conventional method suffers from poor correction results reflected in elevated level of error rate stemming from increased EVM. The effectiveness of our methods also increases as CFO level increases (a), (b) and with higher SNR values (c).

In summary, our approaches to improving channel capacity of a wireless channels utilizing our suite of patented technology shows a drastic improvement over a conventional method, where a severe Carrier Frequency Offset (CFO) is observed due to either a high-degree of Doppler effect or a

LTE Uplink Example:
EVM Improvement using Our Technology over conventional method for correcting Carrier Frequency Offset (CFO) and Sampling Frequency Offset (SFO) shows Potential for **Drastic Data Rate Improvement**

EVM Improvement over Conventional Method

Frequency Offset	100ppb	300ppb	500ppb
SNR = 10 dB	0.06 dB	0.39 dB	0.98 dB
SNR = 20 dB	0.43 dB	2.7 dB	5.2 dB
SNR = 30 dB	2.9 dB	8.9 dB	11.5 dB

severe hardware mismatch. Our approach effectively removes most of the observed CFO and SFO errors (either h/w or Doppler-effect induced) prior to a permanent data corruption resulting in performance comparable to that of a channel with no carrier frequency offset.