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CO-OPERATIVE RF RANGING AND TIME TRANSFER DEFINITIONS FOR MEGA CONSTELLATIONS AND SPACE TRAFFIC MANAGEMENT

Abstract

Satellite conjunctions in space are a major problem for operators and governments due to the lack of coherent and international space situational awareness solutions. The tracking accuracy for two-line elements (TLEs) averages in kilometres with similar error boundaries making it limited for critical satellite collision prediction. Common practice using GPS provides high accuracy from centimetres to metres. However, satellite state data (position and velocity) are often never shared and orbit determination methods provide limited solutions at quantifying near-miss events. In the advent of mega-constellations, there is an urgent need for in-situ measurements to develop real satellite traffic management solutions and associated satellite traffic data standardisation to complement and refine existing techniques.

This research presents a new time of flight (ToF) ranging estimation technique adapted for the increasing low Earth orbit satellite traffic that requires co-operative monitoring. Two methods have been investigated: one-way time transfer (OWTT) which measures propagation time in one single trip. And two-way time transfer (TWTT) which measures propagation time in a single round-trip. Results show that OWTT ranging accuracy requires precise clock synchronisation between two satellites and even a 1.5 s relative clock drift would result in an approx. 200 m ranging error. However, TWTT is not sensitive to relative clock drift and eliminates complex and time consuming clock synchronisation. This is traded for larger system processing delays that result in metre-level ranging errors.

ToF ranging typically requires wide signal bandwidths to achieve metre-level accuracies hence the need for bandwidth efficient techniques like spread spectrum. Direct Sequence Spread Spectrum (DSSS) is utilised to spread a narrow bandwidth signal at a higher data rate PN code. Several PN codes have been implemented, namely the m-sequence, Gold, T2B and T4B. To make impact assessments on these variables, a baseband signal processing setup has been implemented and found that the selection of a PN code has a major impact on ranging errors. This is especially important if the desired operational signal-to-noise is low enough to provide early conjunction warning. For example, using an m-sequence code in a -25-dB baseband channel with 100 kbps resulted in 145 km root-mean square error (RMSE). In contrast, using the T4B code under the same initial conditions resulted in 1.3 km ranging error. Ultimately, a new set of ranging specifications are defined for future RF instrumentation under varying satellite approaches.