Managing noisy and missing measurements in time scale generation for a swarm of nanosatellites

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The issues of measurement noise and missing data will be prominent when considering large-scale constellations of nanosatellites. Synchronization in satellite swarms is achieved by developing a common reference among the satellites by generating a time scale using only the onboard clocks. Two-way transfers are used to measure the clock biases between satellites with a non-negligible level of measurement noise. The level of uncertainty is expected to vary as a function of the inter-satellite distances, which are not necessarily uniformly distributed amongst the swarm. Additionally, abrupt changes can occur in the noise affecting certain links, which results in anomalies in the measurements or missing measurements. To mitigate the negative effects of noisy and missing measurements on the resulting time scale, the redundant measurements available in the swarm should be used as additional information. The greatest amount of timing information is available if each satellite clock can compare itself with every other satellite clock in the constellation.

Assuming that neighboring satellites can communicate their unique clock bias measurements between them, there is a total of $N(N-1)/2$ unique observations available in a swarm of N satellites. When measurement noise is negligible, $N-1$ unique measurements are required to generate a time scale. However, the inter-satellite measurement noise should be reduced before generating a time scale using only onboard clocks. This work aims to use the additional information on the satellite time differences to both reduce the impact of the measurement noise and reconstruct specific missing measurements. Since each clock bias measurement can be written as a linear combination of the other clock bias measurements, the noise can be reduced by using a least squares estimator of the $N-1$ required measurements. If a satellite cannot make clock comparisons with certain other satellites, the same least squares method can be used to estimate the measurements from missing inter-satellite links. To finalize the analysis of missing measurements, a basic proof is shown that the time scale can remain continuous if the weight of a clock with no inter-satellite links is set to zero at the time it disappears and returns from the communication network.

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