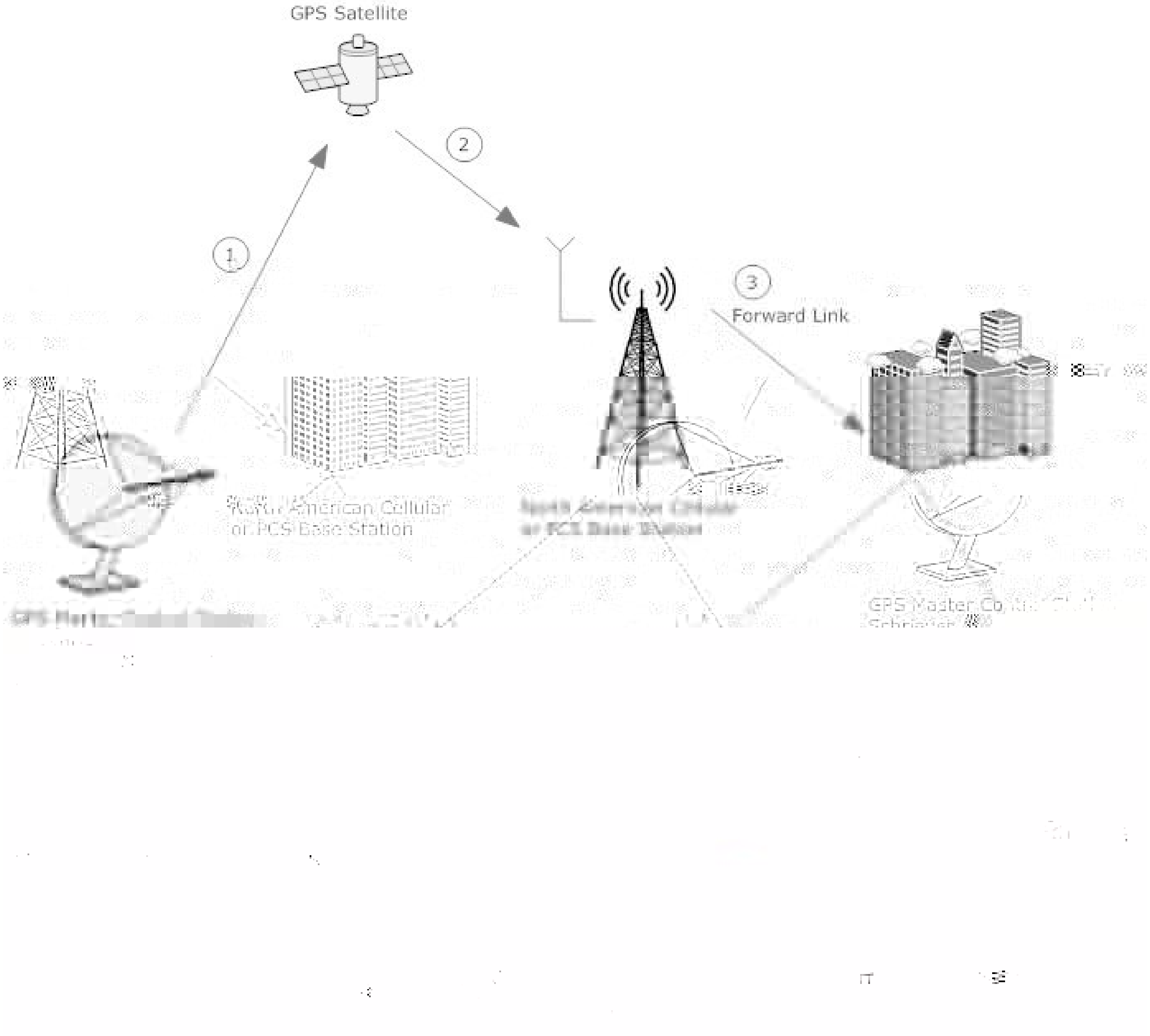
. igure 2 provides an overview of UTC time transfer to - . Ts using C%M& and PTP. Table 2 identifies the time and corrections in the chain. . or the purpose of this paper" the relationship between UTC'US6 9(" UTC' 6 IST(" GMT" UTC" UT2" and T&I are not illustrated.



. igure 2. UTC Time Transfer Using C%M& and PTP

Table 2. Time and Corrections in Time Transfer Chain

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2	GPS Master Control Time : UTC'US6 9(Time 9ffset : 5eap Seconds
0	GPS Satellite Time : UTC'US6 9(Time 9ffset : 5eap Seconds
;	C%M& System Time 'GPS Time Scale(
<	UTC Time 'C%M& System Time Corrected =ith Current 5eap Seconds(

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-.Ts install high speed hardware and proprietary software with high bandwidth connections at the mar!et centers. The co located space provides an advantage over traders that are not co located of several milliseconds" allowing them to identify trading opportunities even at a profit of only >1.12 per share. The -.Ts trade at a rate of more than 2111 per day and it is estimated that up to /2? of daily US e,uity share volume and @1? of total daily trades are from -.Ts A2B. The Commodity .utures Trading Commission 'C.TC(and the Securities 7+change Commission 'S7C(reported on the events of May /" 0121 and identified that starting at 0C<$C2; and lasting only 2< seconds" there were 0@"111 trades attributed to -.Ts AOB. That is nearly 0111 trades per second or one trade every $11 microseconds.

The ma*or e+changes are adding more capacity for this technology by adding more s,uare feet and bandwidth to the centers. They are also going to great lengths to ma!e the access latency e,ual for all the various -.Ts by matching networ! bandwidth" networ! speed and even networ! cable lengths. 9ne of the mar!et centers specifies the mar!et center gateway as ultra low latency 'D211 microseconds(.

Co located -.Ts re,uire precise UTC time to trac! orders in the mar!et by placing timestamps in their buy and sell messages. Most -.Ts have many computer systems running on dedicated 5&6s each 5&6 using one PTP Grandmaster Cloc! and each computer on the 5&6 synchroni)ed to that Grandmaster. These parallel" high speed computer systems must be synchroni)ed for the algorithms to process mar!et buy side and sell side data. The timestamps and synchroni)ation of computers are also used in networ! analys#to an ogy!0nvt aresIAIT Dyse juritionds

Code %ivision Multiple &ccess 'C%M&(is a wireless spread spectrum communication technology used in 6orth &merica by Sprint and Eeri)on. 9ther countries including 3ra)il" China" Forea" India" Gapan" 6ew Healand" -ong Fong and others also use C%M&. 4eferred to as IS #$ C%M&" it competes with technologies such as GSM provided by &T I T. -owever" worldwide GSM has more coverage" and in 7urope" it is the only option. Most smart phones offered in the mar!et today have a GSM and C%M& version available" with some providing dual C%M&JGSM hybrid models for more coverage. Currently GSM and other technologies do not provide precise timing capabilities.

C%M& IS #$ does provide precise timing capabilities. C%M& base stations transmit timing signals that are sourced from GPS timing receivers in order to !eep base stations synchroni)ed to GPS time within 21 microseconds" even during periods of GPS satellite unavailability lasting up to eight hours A<B. & C%M& timing receiver provides precise time when GPS is available" and for critical timing re,uirements such as -.T" C%M& provides a bac!up to GPS. If GPS were unavailable" the C%M& base station continues to provide time and the C%M& receiver maintains the time for -.Ts.

The C%M& receiver is a miniaturi)ed module similar to an 97M GPS receiver and is embedded in the rac!mount PTP Grandmaster Cloc! with an indoor antenna as shown in .igure 0. The receiver is designed to- P w„

. igure ;. C%M& 4eceiver &rchitecture

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PTP is an I777 2$88 defined protocol for synchroni)ing real time cloc!s over a 5&6 to UTC with sub microsecond accuracyA/B. Cloc! synchroni)ation on the 5&6 re,uires at least one master and one slave. Multiple slaves can synchroni)e to a single master. The master cloc! provides synchroni)ation messages that the slaves use to correct their local cloc!s. Precise timestamps are captured at the master and slave cloc!s. These timestamps are used to determine the networ! latency which is re,uired to synchroni)e the slave to the master. There is a synchroni)ation message typically transmitted every two seconds from the master" and a delay re,uest message from the slave less fre,uently. UTC time synchroni)ation is provided at each high speed computer using PTP as shown in . igure 2 '5in! <(.

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Synchroni)ation of cloc!s on a - . Ts networ! is embedded in servers in the co located mar!et centers. Since the servers and trading algorithms are highly secretive" the following analysis of UTC time transfer data is

Measuring networ! synchroni)ed cloc!s on computers and servers is not possible using traditional methods. They do not have cloc! outputs such as 21M-) or 2PPS that can be measured with a scope or analy)er for accuracy or stability. 3ecause of this" most PTP systems rely on statistics logged at each slave. .or the purpose of this paper a PTP hardware measurement cloc! was configured. This cloc! contains the same PTP slave daemon that many -.Ts are using" with a GPS referenced cloc! providing hardware timestamping.

Statistics gathering at a slave cloc! is a simple method of understanding synchroni)ation capability" however it does not directly relate to the actual time of the slave cloc!. -ardware measurements of a slave to master using lab e,uipment such as a time interval counter or oscilloscope are valid techni,ues only if both the master and slave cloc!s provide 2PPS. This method can measure the difference between the phase of the 2PPS pulses. =hile this is valid" it lac!s the ma*or time of day '%ays" -ours" Minutes" Seconds(" and can have an offset of several seconds and not be correlated with the collected data.

.or the measurements presented here" a device was configured with a GPS receiver and a hardware real time cloc!. & time compare register was used to capture the minor 'sub seconds(and ma*or times of the hardware cloc! and the PTP slave cloc!. The time compare was captured at 2/ =[illegible]

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;)< US Commodity .utures Trading Commission and U.S. Securities I 7+change Commission" September ;1" 0121 N% *# , ! - . /0 *1**P. 4eport of the staffs of the C.TC and S7C to the *oint advisory committee on the emerging regulatory issues" =ashington" %C.

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;1< C%G" 0121" N . P" C%M& %evelopment Group" http:CJJwww.cdg.orgJtechnologyJcdmaMtechnologyJaMrossJsystemtime.asp.

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