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# New Prospects for One-way Time Transfer over Satellite

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4 November 2015



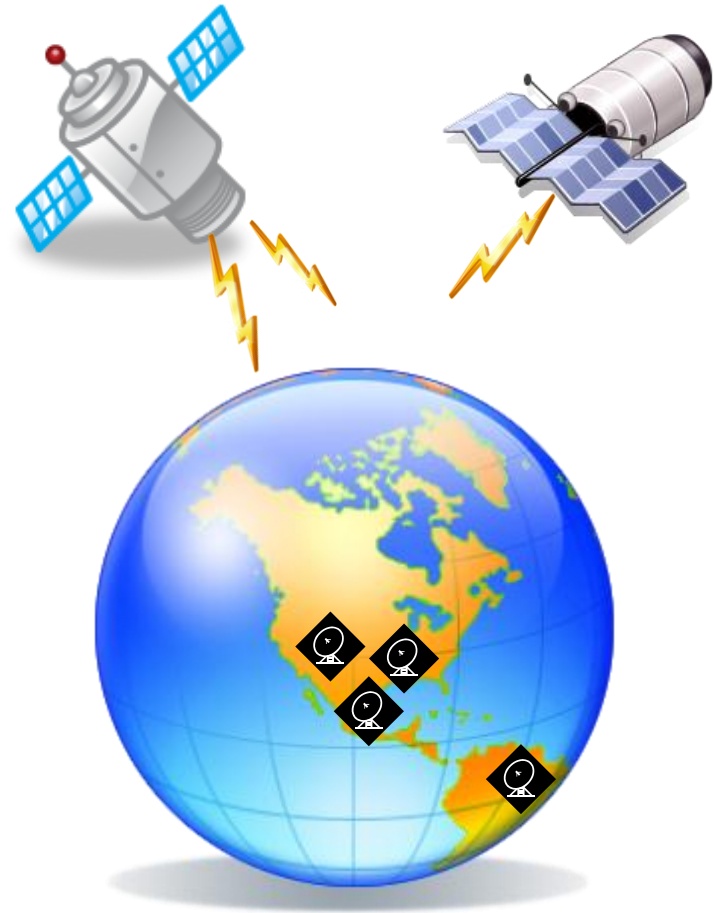
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... a recurring dream, a  
recurring theme...

Time transfer using satellite has  
been explored since at least early  
1970s when synchronization was  
achieved to within  $150 \mu\text{s}^1$

Later trials in 1980s (India), 1990s  
(France), 2000s (South Korea)  
progressively improved accuracy





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THE SUNDAY TIMES

UNIVERSITY  
OF THE YEAR 2015



... GPS revolutionized the field ...

with its capability to provide time to users with a view of a single satellite  
.. a free service  
..wide coverage  
...with the result that systems reliant on GPS time source are everywhere



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Concerns about  
availability of GPS  
system extend to the  
highest levels!

From: The Telegraph,  
14 October

HOME » NEWS » WORLD NEWS » NORTH AMERICA » USA

## US navy returns to celestial navigation amid fears of computer hack

US Navy recruits to learn how to navigate using the stars as America grows increasingly worried about possible hacking of computer navigation systems



3K



6/5



1



156



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Email



The era of celestial navigation ended with the launch of satellites in the 1990s. Photo: Alamy



By Harriet Alexander, New York

3:29PM BST 14 Oct 2015



4,587 followers

It was how Odysseus sailed the seas, how Columbus reached the Americas, and how Lawrence of Arabia found his way across the vast, featureless deserts of the Middle East.



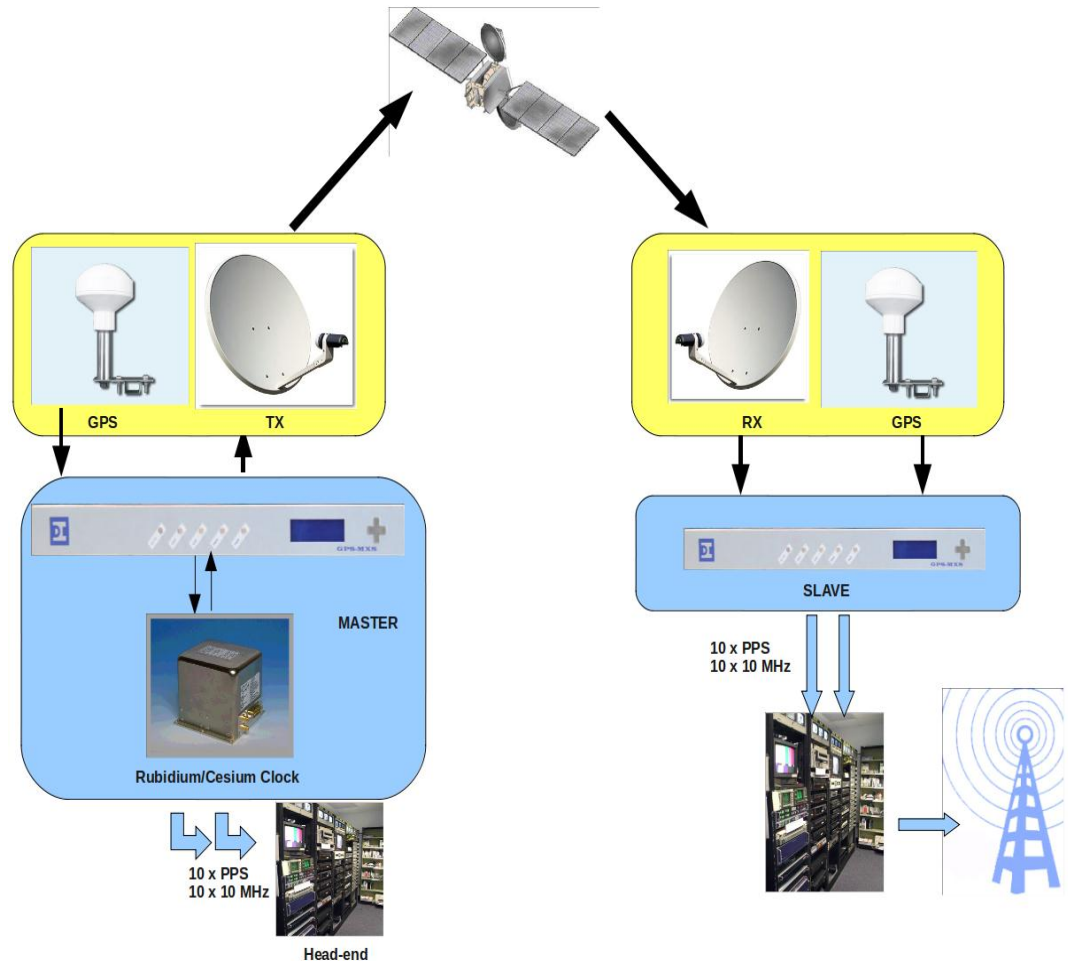
## ..distinguish between time transfer and time source...

Recent developments have focussed on IEEE1588v2 and PTP as the means to providing a reliable accurate timing source for modern mobile networks but while IEEE1588v2 may be able to guarantee accurate transfer of time within certain limits it has nothing to say about the source of that time.....



## ..the time service over geostationary satellite proposal...

- Master station with precision source transmits timing signal over satellite
- Slave stations receive and distribute

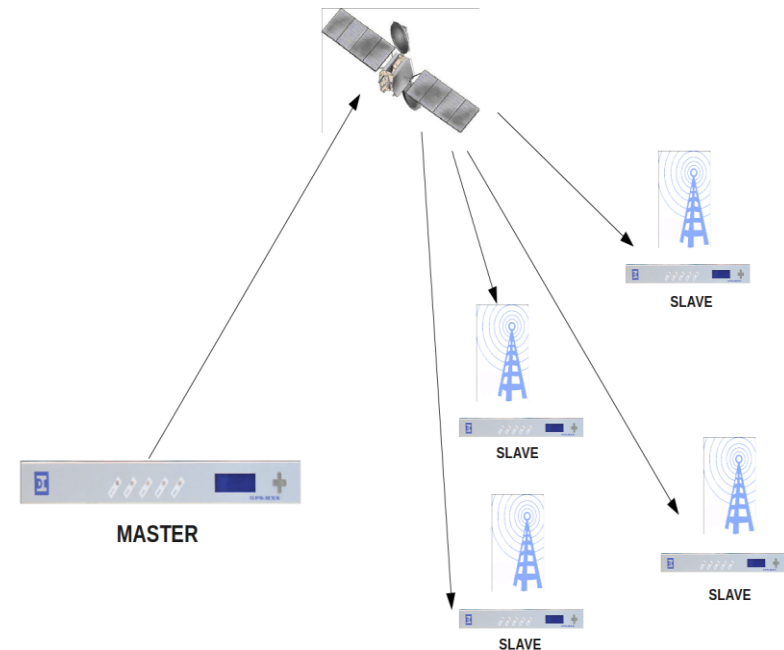






## ..an initial experiment...

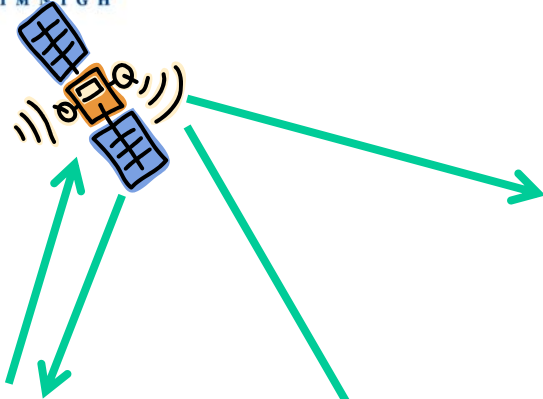
- E1 PPS sent over satellite channel
- One master station
- Three slave stations
- Geostationary satellite used Eurobird 3 (now Eutelsat 33A)





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..some pictures...



Master station



Slave Station

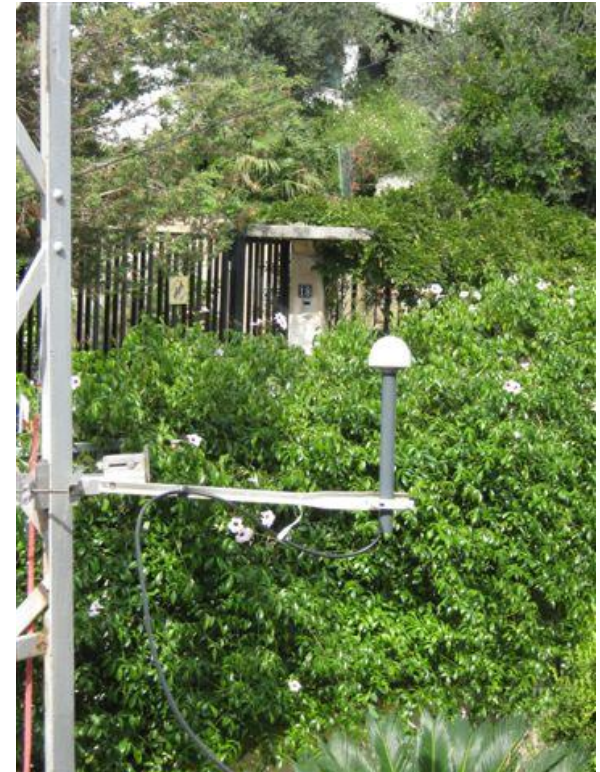




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## .. Slave Station Set-up...





## ..some results from initial experiment...

- Characteristics of timing jitter on received PPS at the three slave stations
- Error had approximately sinusoidal characteristic, peak-to-peak estimated by range

	Station 1 (ns)	Station 2 (ns)	Station 3 (ns)
mean	-642.5	-2927	-4083.4
standard deviation	78.5	98.6	71.99
median	-648	-2928	-3896
range	488	608	472



## ..conclusions from initial experiment...

- Positive and encouraging results
  - Distributed PPS across 900km baseline with  $< 1 \mu s$  jitter
  - The experience shows that such a system is within reach of a commercial operator
  - Key issues uncovered in subsequent analysis may have impacted performance
  - Only one master station + need specialised modem



## ..problem statement ...

- To supply a 1 pps signal within given jitter limits
- Solution approach
  - Supply the signal together with information about the satellite motion to the slave stations
- Potential sources of this information
  - Ephemeris
  - Real-time measurement



## ..single master station...

- Use satellite ephemeris to provide slave stations with an estimate of their range to the satellite
- Enables slave to adjust the timing of the received PPS signal
- Ephemeris data available only at 15-30 minutes intervals
- Requires interpolation



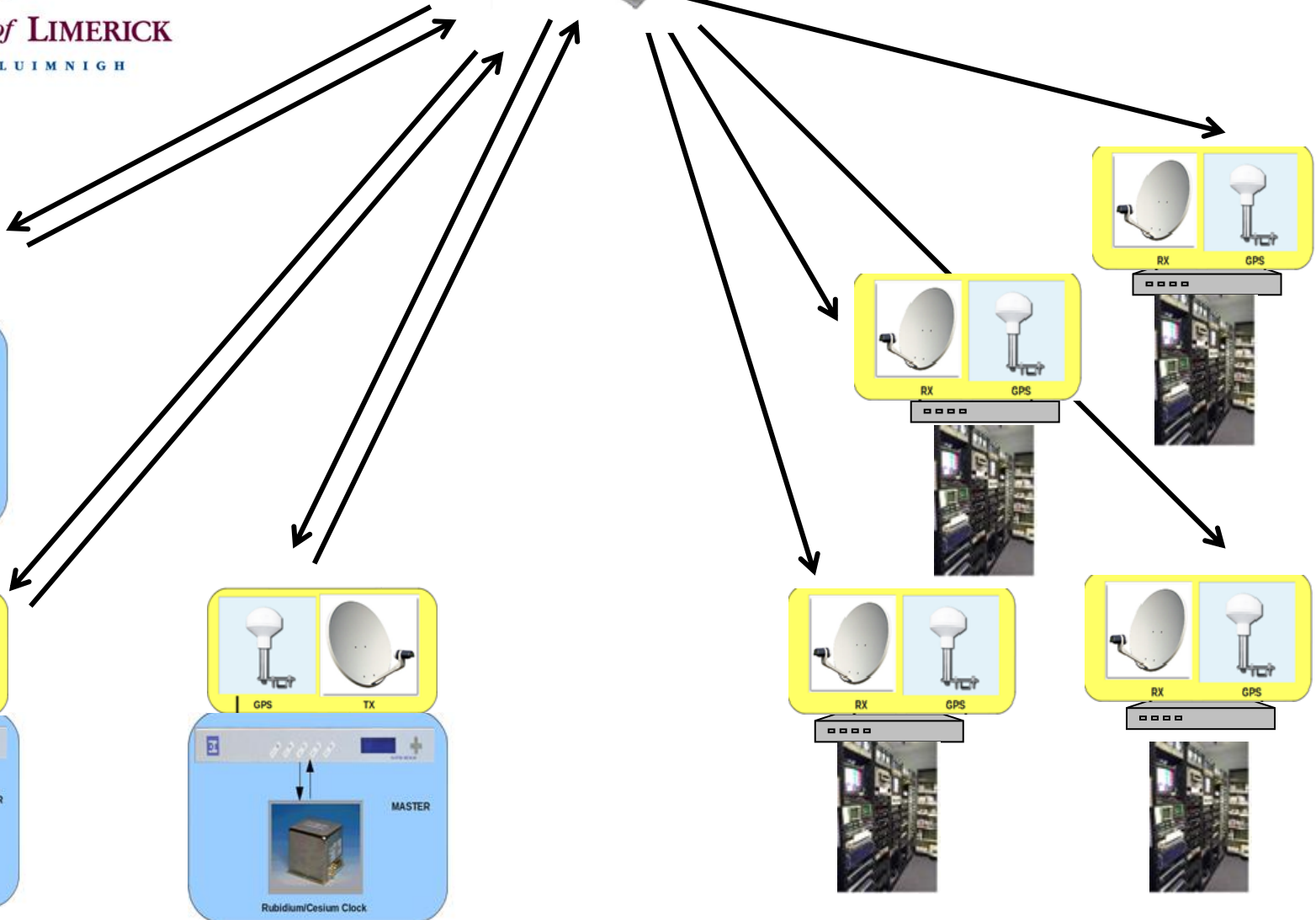


## .. why have three master stations?...

- In principle can track satellite without operator assistance
- Redundancy of master source
- Issues with multiple master stations
  - Independent clocks at stations need to be synchronized
  - Determining or accounting for extraneous delays at stations
  - Impact of errors on satellite position determination
- Previous simulation results highlighted need for accuracy



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## ..problem solving...

- RTT measurement
  - Coarse and fine measurement
  - Key factor is clock rate
    - To measure the RTT a counter is going to be used and with a 100 MHz clock, the resolution available is only 3.0m
    - This neglects other sources of error such as atmospheric effects and clock differences (of which more later)



## ..Sensitivity analysis of satellite position to range estimate errors ...

Of interest is prediction that some master stations more special than others

Master station 1	Master station 2	Master station 3	Error vector
10,50,100,	0	0	-7.3,-36,-73
0	10,50,100,	0	-0.6,-2.7,-5.5
0	0	10,50,100,	-3.2,16,32
50	100	50	47
100	1000	500	180
1000	500	100	735



## ...the proposed solution ...

- Real-time refinement and prediction of satellite motion
- For this a Kalman filter may be used, as reported previously
- Key consideration is the effect of range errors on the utility of the Kalman filter prediction





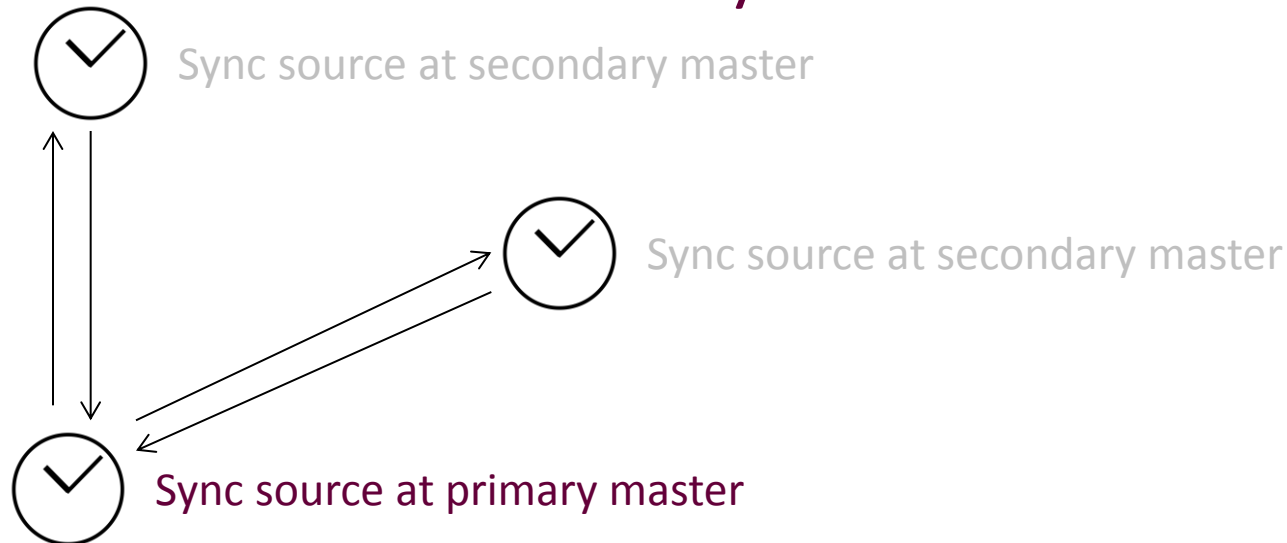
## .. why have three master stations?...

Simulation results showing effect of path measurement error on tracking error

Path noise SD (m)	Kalman filter R matrix (m)	Measurement residual SD (m)	Mean tracking error (m)	SD tracking error (m)
15	15	(17.1,16.8,16.6)	(26,-39,-17)	(318,440,206)
25	15	(26.1,26.7,26.6)	(37,-50,6)	(323,452,311)
50	15	(54.5,52.9,55.5)	(4,-24,-91)	(989,1335,666)
75	15	(81.1,83.8,76.6)	(-537,741,-31)	(1437,1953,883)
100	15	(110,114,110)	(-224,254,-292)	(2044,2738,1632)



.....having three stations, you will need synchronization...



- Must be achieved over satellite link
- Simulations assume the existence of such a correction between range estimates



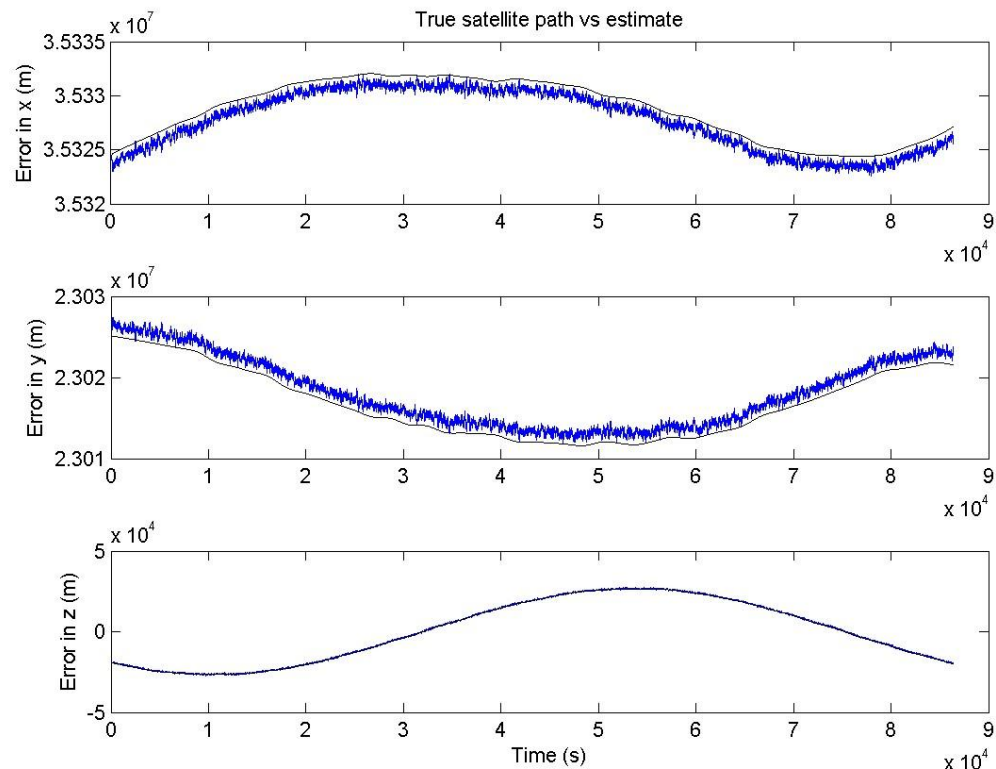
## .. effect of clock synchronization errors...

- KF simulation included a model of clock synchronization between master stations
- The mean error in the clock synchronization can be changed in the model
- The effect of this is to introduce an offset into the tracking depending on which master station is affected



## .. Model predictions...

Performance of  
Kalman filter path  
tracking of x,y,z  
satellite co-ordinates  
with a timing error  
between master  
station clocks

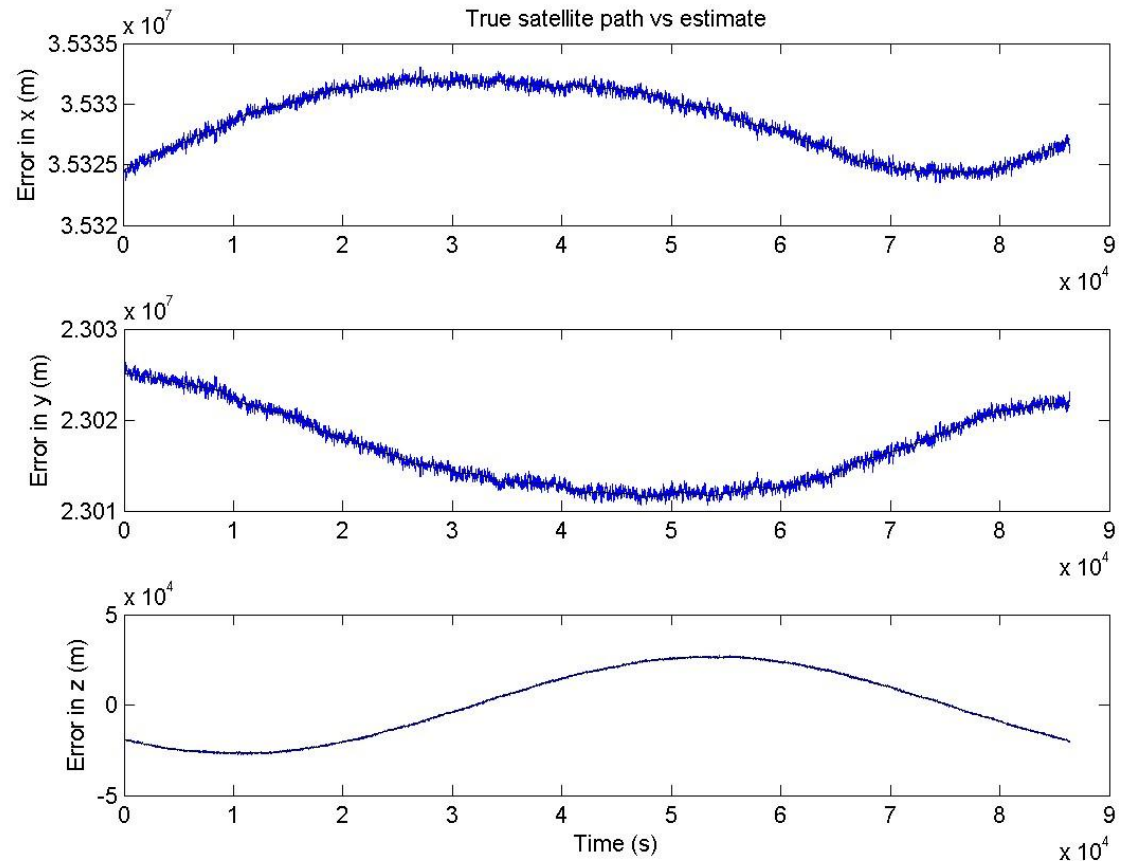




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## .. Model predictions...







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## ..Conclusions advantages of the system...

- Potential to distribute time over a wide geographical area
- ‘Slave’ devices need not be expensive for customers or installation
- Can be piggybacked onto existing technology



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## ..Conclusions progress in system development...

- Satellite modem developed by Mixed Processing Ltd
- Test stations established in Ireland (Limerick, at the University of Limerick) and Italy (Bresso and Asti in Piedmont)
- Initial testing underway using Eutelsat satellite



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..thank you...



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