ITU-BIPM Workshop
“Future of International Time Scale

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# Conception, Definition and Realization of Time Scale in GNSS

Han Chunhao
*Beijing Satellite Navigation Center*
*Beijing 100094, China*

Email: hch203@163.com

# Time Conceptions

- **What is Time?**

  - a significant,challenging question for all philosophers and scientists

  Plato, Aristotle, Kant, Newton, Einstein...

- **Newtonian Time**

  absolute, independent to any observer /space

. same for everyone and everywhere

- **Relativistic Time**

  relative, dependent to the observer/space

  ( space and time are merged into spacetime)

  different observers have different times for an event, also for a time interval between two events.

  so called "proper time" of observer

# Time Conceptions

- **Coordinate Time**

  a timelike variable, or a special observer's proper time. defined for a spacetime coordinate system.

  different reference systems have different time coordinates. such as:TCG,TT for geocentric coordinate systems, and TCB ,TDB for solar barycentric coordinate systems

  A public time standard must be a coordinate time.

# Time Definitions

- **The Geocentric coordinate Time(TCG)**

  coordinate time of non-rotating geocentric reference systems

  ~ proper time of the geocenter assumed with no earth gravitational field

- **The Terrestrial Time(TT)**

  coordinate time of non-rotating geocentric reference system, diferent to TCG by a scale factor

$$dTT/dTCG \equiv 1 - L_G \quad L_G \equiv 6.969290134 \times 10^{-10}$$

  ~ proper time of the Geocenter assumed with a gravity potential just like on the geoid (or mean sea level )

# Time Definitions

- **SI second**
  - ✓ UT second (before 1960)

    the fraction 1/86 400 of the mean solar day

  - ✓ ET second(1960,CGPM 11，Resolution 9)

    the fraction 1/31,556,925.9747 of the tropical year for 1900 January 0 at 12 hours ephemeris time.

# Time Definitions

- **SI second**
  - ✓ Atomic Second

(1967/1968,CGPM 13, Resolution1)

The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium 133 atom.

*It was designed for continuity with ET*

in 1997 the CIPM affirmed that:

The definition refers to a caesium atom at rest at a temperature of 0 K.

# Time Definitions

- **SI second**
  - **TAI second**

    Atomic Second on the geoid(mean sea level)

The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium 133 atom at rest on the geoid at a temperature of 0 K .

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# Time Realizations

- **Apparent Solar Time**

  -apparent solar position on the sky.

  basic time unit: solar day, tropical year

  ***easy to observe, but not uniform***

  ***dependent to the position observer***


# Time Realizations

- **Mean Solar Time (*Universal Time* )**

  basic unit: mean solar day , refered to a fictitious "mean sun"

  ***local time and Universal Time , Time Zone***

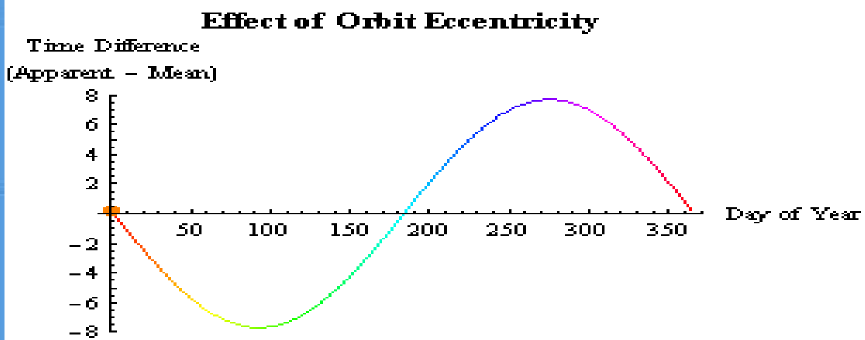
  ***more uniform than the aparent solar time , but still has irregularity caused by the earth rotation***

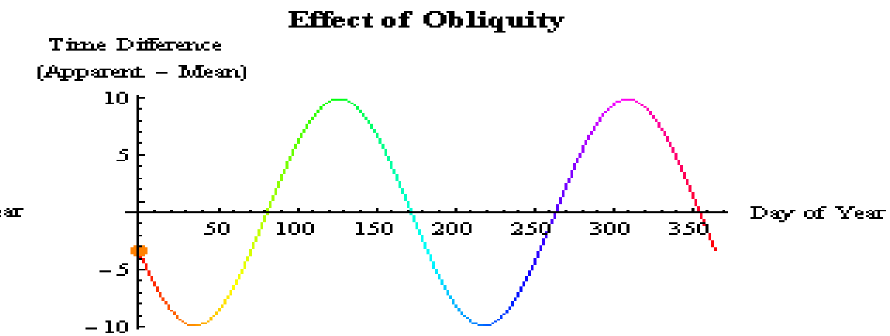
  ***uncertainty: 1E-8***

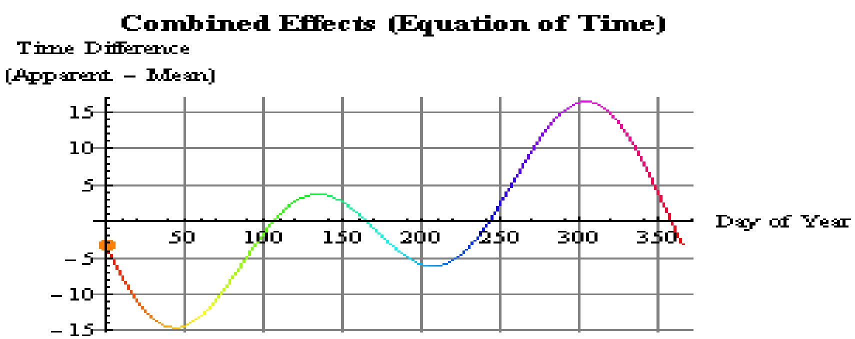
- **Equation of Time**

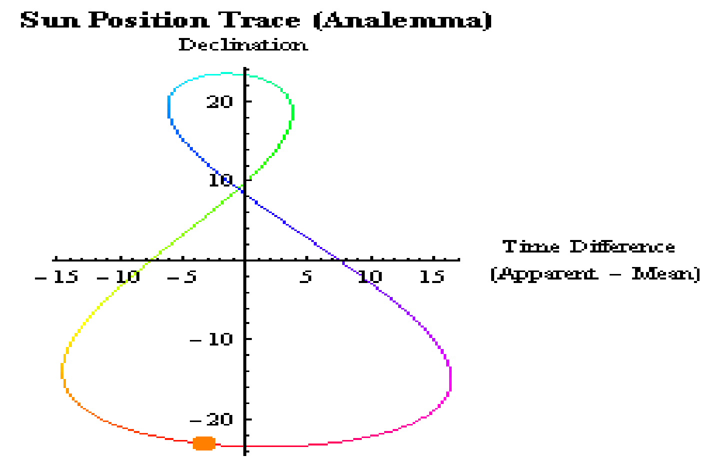
  diference of solar time to mean solar time

$$(T_{\Theta} - T_{\bar{\Theta}}) \in (-14^{m}15^{s}, +16^{m}25^{s})$$


Effect of Orbit Eccentricity
Time Difference
(Apparent – Mean)
8
6
4
2
–2
–4
–6
–8
50 100 150 200 250 300 350
Day of Year


Effect of Obliquity
Time Difference
(Apparent – Mean)
10
5
–5
–10
50 100 150 200 250 300 350
Day of Year


Combined Effects (Equation of Time)
Time Difference
(Apparent – Mean)
15
10
5
–5
–10
–15
50 100 150 200 250 300 350
Day of Year


Sun Position Trace (Analemma)
Declination
20
10
–10
–20
–15 –10 –5 5 10 15
Time Difference
(Apparent – Mean)

**Wikipedia,**

# Time Realizations

- **Ephemeris Time (ET)**

  adopted in 1952 by the IAU and superseded in the 1970s.

  basic unit: ET second

  ***in order to define a uniform time based on Newtonian theory, but affected by observation errors.***

  *Although ET is no longer directly in use, it leaves a continuing legacy. Its successor time scales, such as TT, TAI, were designed with a relationship that "provides continuity with ephemeris time". it was used for the calibration of atomic clocks in the 1950s.*

# Time Realizations

- **International Atomic Time(TAI)**

  running since 1958

  basic unit: SI second, *with a relationship to ET*

  *using an ensemble of atomic clocks spread over the world*

  *to match the rate of proper time on the geoid*

  *more precisely uniform than ET,*

  *the best realization of TT*

  *TT =TAI+32.184s*

  *uncertainty:<1E-14*

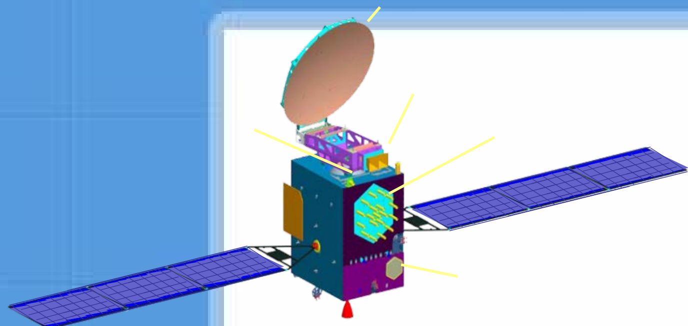
# GNSS Times

- **Work principle**

  *three segments:* space segment (satellite constellation), ground control segment (a master station, uplink stations and monitor stations) and user segment (user receivers).

  *basic observables:* pseudo-ranges.

  *navigation information:* satellite orbits, clock offsets and ionospheric time delay



# GNSS Times

- **System Time**

  **The coordinate time of geocentric reference systems: TT**

  **basic unit: SI second**

  ***Time synchronization based on TT***

  ***GNSS Times ,such as GPST ,BDT are realizations of TT.***

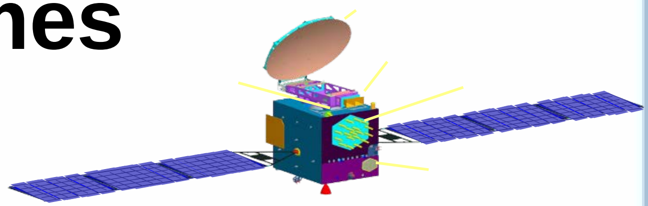
$$GPST \cong TAI - 19s = TT - 51.184s$$

(uncertainty:<30ns)

$$BDT \cong TAI - 33s = TT - 65.184s$$

(uncertainty:<100ns )

# GNSS Times



- **Time Service**

  **Standard Time :UTC**

  **Nav. Data: UTC parameters**

  number of leap seconds: $\Delta t_{LS}$

  time offset parameters ( modulo 1s)

  $$\Delta t_{ST} = T_{GNSS} - UTC = A_0 + A_1 (T - T_0)$$

  $$UTC = T_{GNSS} - \Delta t_{LS} - \Delta t_{ST}$$

  *for example:*

  $$UTC(USNO) = GPST - \Delta t_{LS}^{GPS} - \Delta t_{ST}^{GPS}$$

  $$UTC(BSNC) = BDT - \Delta t_{LS}^{BDS} - \Delta t_{ST}^{BDS}$$

  $$(UTC(BSNC) - UTC < 100ns)$$

  *BSNC: Beijing Satellite Navigation Center*

# Time Standards

- **Coordinated Universal Time (UTC)**

  an atomic time scale designed to approximate UT1.

  basic unit: **SI second**

  ***differs from TAI by an integral number of seconds. kept within 0.9 s of UT1 by the introduction of leap second***

  ***up to day***

  ***UTC=TAI-35s***

- **Standard time**

  **civil time in a region,** deviates a fixed, usually a whole number of hours from UT1, now usually UTC.

  The offset is chosen such that a new day starts approximately while the sun is at the nadir(midnight)

# The Variability of UT1

- **The variety of UT1 referred to TT**

$$\Delta T = UT1 - TT = a + b\,t + c\,t^2$$

**note:**

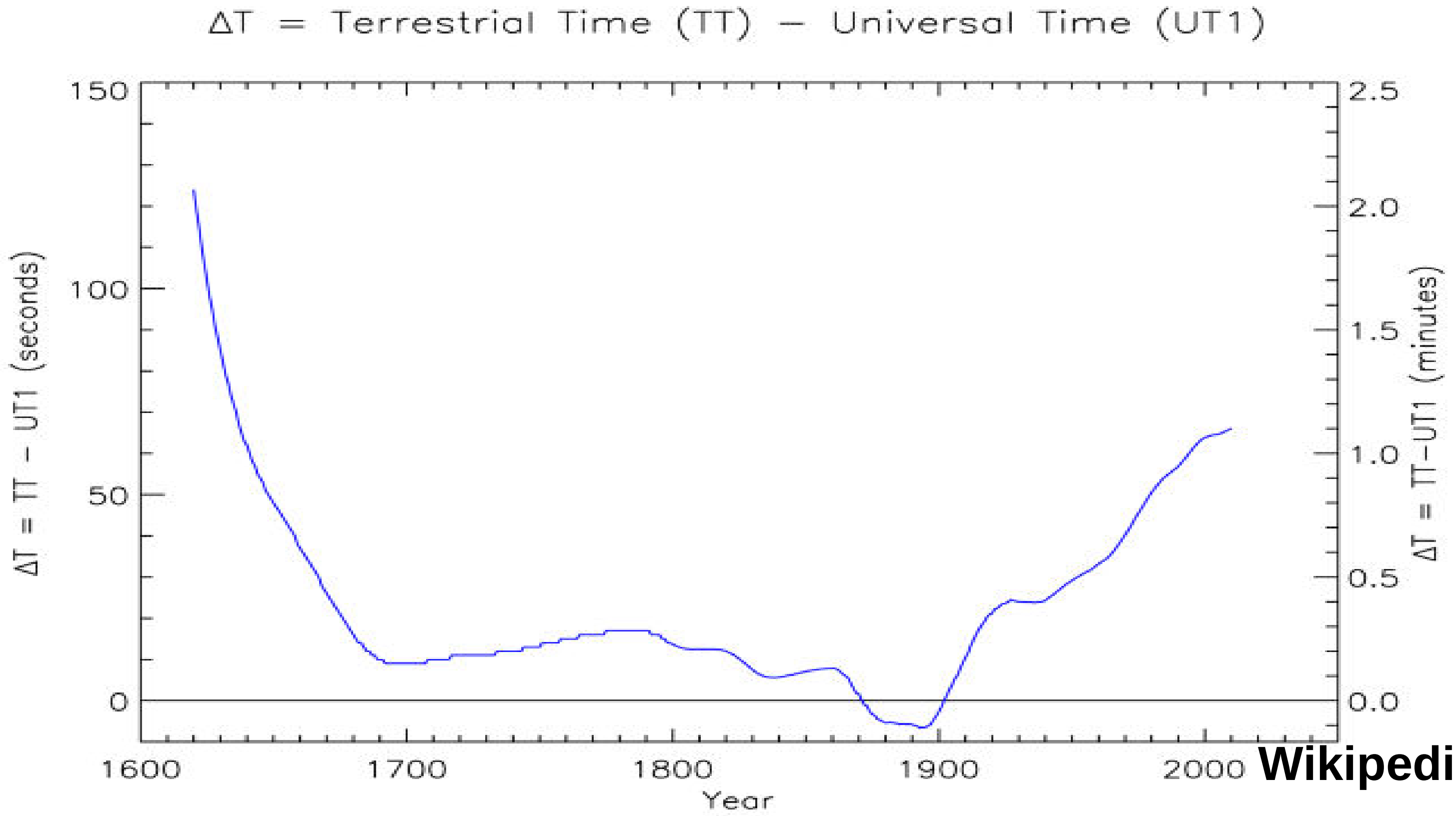
$b, c$ not invariable constant !

$\Delta T$ not predictable in fine detail

***There no ways to give a rigorous relationship between UT1 and TT.***

# The Variability of UT1

- **The observed results**




**Wikipedia**

Observed values of ΔT = TT – UT1 (seconds)
(values before 1955.5 based on n' = 26.0 "/cy/cy)

**Wikipedia,**

| year | +0 | +1 | +2 | +3 | +4 | +5 | +6 | +7 | +8 | +9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1890 | –5.87 | –6.01 | –6.19 | –6.64 | –6.44 | –6.47 | –6.09 | –5.76 | –4.66 | –3.74 |
| 1900 | –2.72 | –1.54 | –0.02 | 1.24 | 2.64 | 3.86 | 5.37 | 6.14 | 7.75 | 9.13 |
| 1910 | 10.46 | 11.53 | 13.36 | 14.65 | 16.01 | 17.20 | 18.24 | 19.06 | 20.25 | 20.95 |
| 1920 | 21.16 | 22.25 | 22.41 | 23.03 | 23.49 | 23.62 | 23.86 | 24.49 | 24.34 | 24.08 |
| 1930 | 24.02 | 24.00 | 23.87 | 23.95 | 23.86 | 23.93 | 23.73 | 23.92 | 23.96 | 24.02 |
| 1940 | 24.33 | 24.83 | 25.30 | 25.70 | 26.24 | 26.77 | 27.28 | 27.78 | 28.25 | 28.71 |
| 1950 | 29.15 | 29.57 | 29.97 | 30.36 | 30.72 | 31.07 | 31.35 | 31.68 | 32.18 | 32.68 |
| 1960 | 33.15 | 33.59 | 34.00 | 34.47 | 35.03 | 35.73 | 36.54 | 37.43 | 38.29 | 39.20 |
| 1970 | 40.18 | 41.17 | 42.23 | 43.37 | 44.49 | 45.48 | 46.46 | 47.52 | 48.53 | 49.59 |
| 1980 | 50.54 | 51.38 | 52.17 | 52.96 | 53.79 | 54.34 | 54.87 | 55.32 | 55.82 | 56.30 |
| 1990 | 56.86 | 57.57 | 58.31 | 59.12 | 59.99 | 60.78 | 61.63 | 62.30 | 62.97 | 63.47 |
| 2000 | 63.83 | 64.09 | 64.30 | 64.47 | 64.57 | 64.69 | 64.85 | 65.15 | 65.46 | 65.78 |
| 2010 | 66.07 | 67.1(8) | 68(1) | 68(2) | 69(2) | 69(3) | 70(4) | 70(4) | – | – |
| year | +0 | +1 | +2 | +3 | +4 | +5 | +6 | +7 | +8 | +9 |

- **The predictor formula (**F Espenak & J Meeus,2006 **)**

| | | |
|---|---|---|
| 1900 to 1920 | $-2.79 + 149.4119\,u - 598.939\,u^2 + 6196.6\,u^3$ | (year – 1900)/100 |
| 1920 to 1941 | $+21.20 + 84.493\,u - 761.00\,u^2 + 2093.6\,u^3$ | (year – 1920)/100 |
| 1941 to 1961 | $+29.07 + 40.7\,u - u^2/0.0233 + u^3/0.002547$ | (year – 1950)/100 |
| 1961 to 1986 | $+45.45 + 106.7\,u - u^2/0.026 - u^3/0.000718$ | (year – 1975)/100 |
| 1986 to 2005 | $+63.86 + 33.45\,u - 603.74\,u^2 + 1727.5\,u^3 + 65181.4\,u^4 + 237359.9\,u^5$ | (year – 2000)/100 |
| 2005 to 2050 | $+62.92 + 32.217\,u + 55.89\,u^2$ | (year – 2000)/100 |
| 2050 to 2150 | $-205.72 + 56.28\,u + 32\,u^2$ | (year – 1820)/100 |

# On The Future of UTC

- **Questions and discussions**

✓ **Do we really need a uniform time scale as the standard time which is close enough with the solar time(UT1) ?**

**yes, certainly**

✓ **How much difference between UTC and UT1 can be tolerated?**

- **time diffence:**

  **1 minute or 10 minutes?**

- **frequency deviation?**

  **1E-6, 1E-7 or 1E-8?**

# On The Future of UTC

- What method is better to make them consistent?
  - time adjustment:

    leap second, leap minute, leap hour?
  - frequency adjustment:

    adjustment the frequency offset within a certain range at a fixed time?

# On The Future of UTC

- **Personal suggestions:**
  - ✓ **Stop  the leap second**
  - ✓ **Maintain the continuity of UTC**
  - ✓ **Adjustment the frequency of UTC once a century, and keep the unit of UTC to be consistent with that of UT1 within 1E-7.**

**Define UTC in the  form:**

$$UTC = (1 - L_{cyi})(TT - TT_{cyi}) + a_{cyi}$$

# On The Future of UTC

- **Personal suggestions:**

**and $L_{cyi}$ Satisfies:**

$$|\frac{dUT1}{dTT} + L_{cyi} - 1| \leq 1E-7?$$

**In this century, wen can simply let**

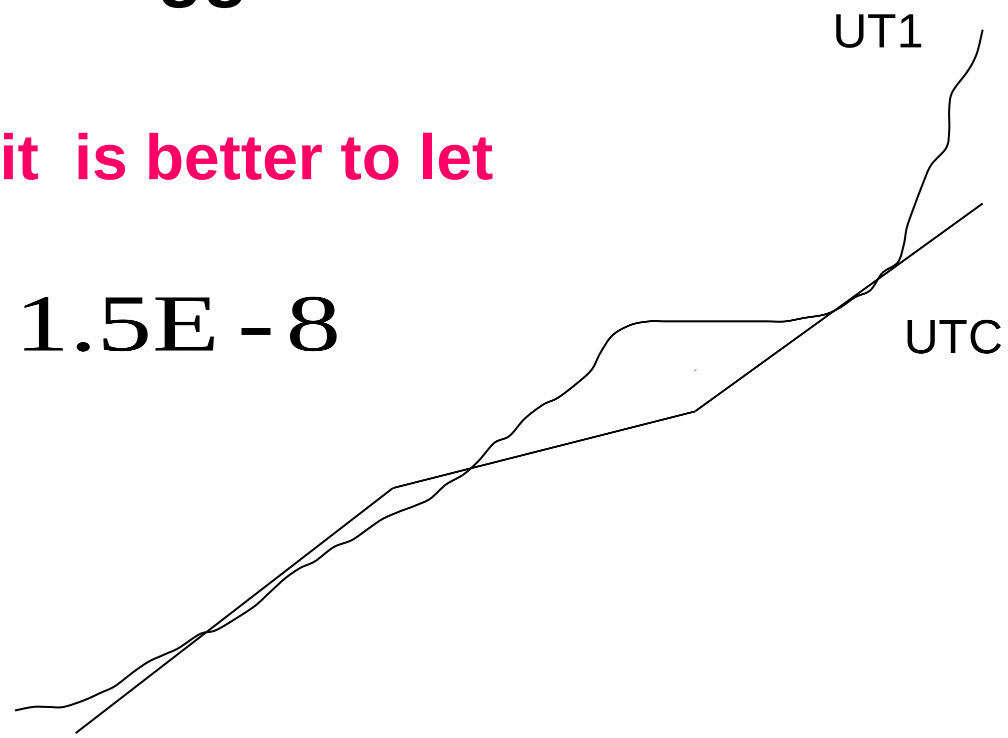
$$UTC = TT - 67.184s = TAI - 35s$$

# On The Future of UTC

- **Personal suggestions:**

**Maybe it is better to let**

$$L_{21} = 1.5E-8$$



# Primary viewpoints

(1) A continuous and uniform time scale is the essential goal of science and technology. The evolvement of standard time from the apparent solar time to the mean solar time, and to UTC fully revealed the desire of human being.

(2) The negative impacts of the irregular insertion of leap seconds are increasing with the development of computer and automation technology. So the requirement for eliminating leap seconds is not only urgent but also reasonable.

# Primary viewpoints

(3)Though the evolution of standard time is an inevitable trend with the development of time scale, but the redefinition of UTC should be treated with caution, seeking benefits and avoiding disadvantages.

(4)  As a base of world-wide  time standard, UTC must have the coordinate function for UT1 and TAI, so the name and continuity of UTC should not be changed.

# Primary viewpoints

(5) Uniform and close to the solar time are important requirements for civil time. Then the definition and realization of standard time must keep some relations to the mean solar time.

(6) The elimination of leap seconds will break UTC the close relation to UT1. But as an approximation of UT1, UTC is used in many fields, such as astronomy, geodesy, space activities, then some online software should be updated.

# Primary viewpoints

(7) Global navigation satellite  systems should disseminate the earth orientation parameters, include the UT1 parameter.

(8) The elimination of leap seconds maybe have no negative impacts on the operation of Beidou system, it is convenient not only to the operator, but also to the users.

Thank you

for your attention