Human Time-Scale Duty Cycle for Opportunistic WiFi Based Mobile Networks

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***Abstract*—Despite the great interest received by the smartphones in opportunistic networks context, the requested energy toll still remains one of the prominent inhibiting factors to the real deployment of such technology.**

In this paper we evaluate a on-off approach devised to provide intermittent (but synchronized) WiFi communication across opportunistically connected devices while saving energy. Differently form classical duty cycle approaches that are implemented at the protocol/network level, we devise a "human time-scale" duty cycle that can be implemented as an overlay system service at the application level. The relatively large time-scale allows to simply keep a loose synchronization between terminals, without requiring any changes in the default operating system or system internals of commercial mobile phones. With reference to Android devices, we analyze the effects of varying such duty cycle in terms of the feasibility of the synchronization requirements as well as the energy gain obtained in order to find the trade-off for the different state settings. For these values, we evaluate the loss of discovered contacts using the data coming from real human mobility traces.

Keywords*—*Opportunistic Networks, Energy Saving, Delay Tolerant Network, Android, Duty Cycle

I. Introduction

The increasing penetration of smartphones with relative large storage capacity and extended communication capabilities (UMTS, LTE WiFi, Bluetooth, etc.) opens new networking dimensions. In this vein, the opportunistic networks arise as conceptual infrastructures which take advantage of the user's mobility to deliver data by a store-and-forward paradigm. Data messages are stored in the terminals and forwarded when a connection with another terminal is available: thus the "meetings" among users are *transmission opportunities* for the network. This kind of opportunistic networking has been largely studied and considered useful in various scenarios such as disaster recovery [1] [2] or for mobile network (3G/4G) data offloading purposes [3].

However terminals have to continuously use the wireless network to discover each other and as a consequence the wireless interfaces rapidly become the largest energy consuming components in mobile device. This gives rise to the need for a clear negotiation between saving energy and providing connectivity through opportunistic contacts in the mobile system.

Many works have selected the Bluetooth as the "best" technology for opportunistic networks just considering the energy consumption as the decisive factor in the choice. On the other hand, Bluetooth, has many other limitations, such as a long inefficient discovery process or the paring procedure, making it a bad candidate for mobile scenarios [4]. A technology that would facilitate interaction between the nodes and, consequently, the realization of opportunistic network is WiFi. Unfortunately, keeping the WiFi interface constantly active causes excessive consumption of energy which precludes its use in actual implementations.

An all but new solution to save energy is the introduction of a duty cycle in the network operations. This approach is heavily used in sensor networks but has been also proposed for Delay Tolerant and Opportunistic Networks. However proposed duty cycle based techniques are integrated at the "protocol" level (networking or switching levels), requiring a close coupling with the existing wireless technologies. Considering that the transmission opportunities of an opportunistic network are related to user mobility we evaluate the introduction of a "human time-scale" duty cycle to control the network operations (in particular the node discovery operations) i.e. the time-scales considered for the duty cycle is in the order of seconds.

Clearly such a solution can be implemented at the application level as an operative system service, without requiring a tight integration with the underlying wireless technologies involved in the communication. Moreover, the relatively large time-scale allows to create an almost-synchronous network keeping a loose synchronization between terminals that can be achieved using standard network synchronization protocols such as NTP. All devices have to be coarsely synchronized and they turn on and off the wireless interface simultaneously. We show how this technique can be effectively implemented in WiFi opp-nets and how a proper dimensioning of the on-off behavior of the wireless interface can save a lot of energy without significantly reducing the contact probability with other users. We will show that besides mere consumption of the wireless transmission and reception chain, a significant part of the drained energy have to be accounted to the information processing and hence into the way the on-off behavior is implemented. In order to discuss this point we present some real Android implementations, showing the difference (in terms of consumed energy) between different approaches that implement the duty cycle technique.

The paper is organized as follow. Section II introduces and discusses the proposed on/off approach. Section III presents the trade-off between the energy gain that can be achieved introducing the duty cycle in real Android smartphones and the reduction in the meeting probability obtained by the reality mining traces. A review of the related works is reported in section IV. Finally conclusion are drawn.

II. THE HUMAN TIME-SCALE DUTY CYCLE

Reference Scenario

We consider the following reference scenario: a set of users is equipped with their smartphones on which one or more delay tolerant applications ("apps") are installed. The mobile devices have WiFi connectivity and they can communicate when the radio link is available. Throughout this paper we call these events *meetings* and we characterize them by their duration, *contact duration* (s), and frequency (s^{-1}), related to the *inter-meeting time*. When a *meeting* occurs, the delay tolerant applications may exchange data.

Given that we want to support challenge scenarios with high user mobility, we choose to focus on the WiFi ad-hoc mode (IEEE 802.11 Independent Base Service Set, IBSS) that allows fast link set up and direct connection with relatively large capacity [5].

Besides the local WiFi connectivity, we assume that the smartphones are connected to the Internet using the 3G/4G networks, as in fact happens in almost any urban environments. We will use this assumption only for the synchronization part as will be discussed later on in this section.

Description of the addressed problem

In this scenario, a relevant share of total consumed energy is accountable to the discovery phase [6]. For instance, let us consider a very simple opportunistic application for *music sharing* that periodically searches in the surrounding for other nodes to exchange the shared music files with them. This requires phones to periodically send requests or presence packets (more generically, *meta-data*) and keep the radio interface *"always on"* only for exploiting the connectivity provided by *few meetings* because the opportunistic contacts can occur anytime. This simple approach presents a high price in terms of energy consumption: keeping the WiFi radio always on significantly drains the battery, as experimented in practice and studied in several works such as [7]. Are there any alternatives?

The sleep/awake approach

If we give a closer look at the statistics of the *meeting duration* in real world cases (for instance by analyzing some real world traces coming from the MIT reality mining [8] or from the HAGGLE project [9]), we find out that the time scale of the relevant parameters (e.g. contact duration, inter-meeting time) is far greater than the actual communication needs for the opportunistic environment. For instance, users typically meet each other for several seconds whilst the time needed to transfer meta-data (usually few kBytes of data) using WiFi is far less than one second [10]. So the radio interfaces can be turned off to save energy for some part of the time.

For this reason, we propose the duty cycle scheme depicted in Fig. 1 in which the state of radio interface periodically cycle between:

- **OFF state**: when the WiFi is turned off and a node can not transmit or receive packets. A node remains in this state for T_{off} seconds;
- **ON state**: when a node is active and able to communicate with its neighbors (if they are in the ON state too). A node remains in this state for T_{on} seconds;

Clearly this strategy can be effectively adopted if *ALL* the terminals wake up at the same time thus requiring a global synchronization that typically is hard to achieve in a general context. However this constraint in our context is mitigated by the fact that the opportunistic meetings occur accordingly to a human mobility pattern. Thus we do not need a *protocol time-scale* accuracy (e.g. microseconds) but a *human time-scale* accuracy (hundreds of milliseconds or even in the order of seconds).

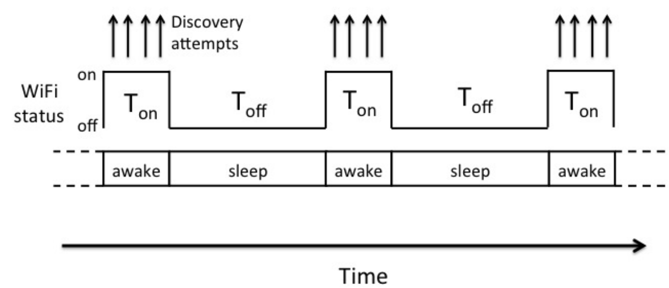

Fig. 1. The devised strategy: periodically turning on and off the WiFi interface, implementing a duty cycle for save energy.

Protocol operations

With reference to Figure 1, the proposed protocol acts as follow:

- For any given pair T_{on} and T_{off} every node starts cycling in a way to be in the ON state when the other phones are ON too. This can be easily achieved by using their internal clock time according with a pre-defined shared rule. For instance if T_{on} = 5s and T_{off} = 55s, the rule could be to keep the interface ON the first 5 seconds of each minute.
- During the ON period, every node frequently (e.g. one packet per second) emits meta-data discovery packets (e.g. queries, hello packets, etc.) and listens for other nodes packets.
- On packet arrival, each node could decide to perform application dependent operations such as initiate a file transfer activity with the newly discovered peer. The occurrence of such operations could prevents the nodes to switch to the OFF state, if they last more than the awake period. Clearly this does not impact on the nodes synchronization. There is just a conditional control in the process that periodically turn ON and OFF the radio interface so that it does not turn OFF the radio interface if some activities are ongoing.
- When the ON phase is terminated and no other communication is in progress, the node go in the OFF state by turning its WiFi radio interface OFF for T_{off} seconds.

The problem of synchronization

There are many ways that can be pursued to achieve synchronization among smartphones. A cheap way to manage synchronization consists in using the native 3G protocols such as NITZ [11]. However NITZ provides a too coarse synchronization whose accuracy is in the order of minutes besides other problems regarding its support by vendors and operators that make it a bad candidate for our purposes. On the other hand, GPS, currently available on almost the totality of the commercial smartphones, could be used to provide a high precision of synchronization that we pay with a relevant energy consumption (e.g. an increase of 50% with respect of the power consumption of a smartphone executing an audio playback, as shown in [12]) and a slow and not always available synchronization that is conditioned to the satellite acquisition.

A third alternative is to use the Network Time Protocol, NTP, to periodically synchronize against a NTP remote server. This solution appears the right one for two reasons: i) it is already in use on several smartphone: for instance, Android based smartphones currently synchronize by default every 24 hours with a server [1], and ii) NTP typically assures a precision in the order of few milliseconds under typical network conditions (e.g. network jitter) [13] that fully satisfy our requirements.

Then the question is how often we have to synchronize with a server and if the default resync time of 24h is enough for our purposes. To answer to this question we need to analyse the clock skew. Indeed, as we will see at the end of this section, this dramatically varies across different smartphones and for different operation modes (in charge, standby etc.), up to several milliseconds in 24h.

The clock drift estimation

We tested the clock drift on two different smartphone: a Samsumg Galaxy SII and a LG Optimus One P500, using the testing methodology of [14] (to which we demand for a dedicated study on clock skew in smartphones). Basically we set up a server that periodically (every 5 minutes sec) sends an ICMP Timestamp Request to the phones and log the time difference between its current time and the timestamps obtained by the clients. While our server is maintained frequently synchronized via NTP with a time server, the mobile phones are disconnected from Internet, in order to prevent their automatic synchronization.
The mobile phones are directly connected to the server via WiFi (the server is the access point) and we monitored the round trip time of the ICMP requests to exclude possible network problems due to jitter.
We repeat the experiments for each phone changing its operation mode between *in charge* (phones are in charge) *standby* (phones are idle and their displays are turned off) and *active* (we used an app, called "Caffeine", that prevents the phones from going to standby, and keeps the display and the CPU always active).
In figure 2 and 3 we show the results of these experiments. As we can see, the clock drift measured while the phones are in charge or active is almost linear with small fluctuations around its mean. The drift measured while the phones are in standby presents a higher variance that we accounted to some internal power saving procedures (the peaks *do not* corresponds to packets with high round trip times) that we expressly don't want to prevent but to *coexist with*.

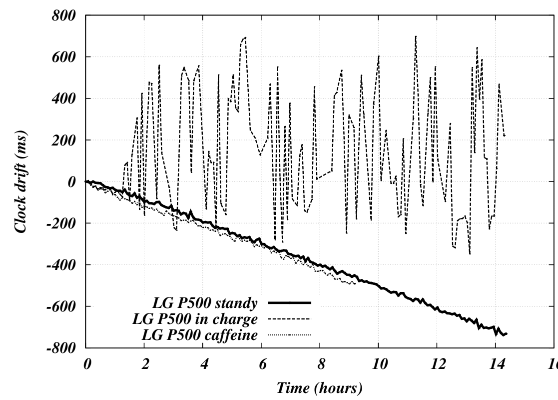

Fig. 2. Clock drift measurement of LG Optimus One P500.

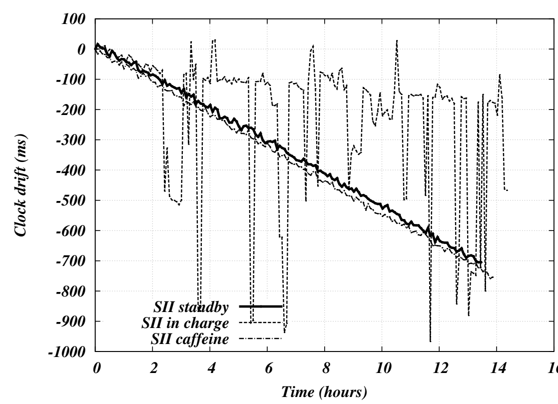

Fig. 3. Clock drift measurement of Samsung Galaxy SII.

For the devices we considered, in all the presented cases, the clock skew is limited (around to) few (one or two) seconds per day that suggest us to conservatively set the T_{on} time to 5s throughout this paper.

III. Performance evaluation

In this section we present the improvements in terms of battery duration that can be achieved implementing the proposed solution (sec. III-A).
Clearly to a lower duty cycle corresponds an improvement in terms of battery duration, however, the more time we keep the radio interface off, T_{off}, the more is the probability that we could miss an encounter whose duration is minor than T_{off}. This is the price to pay for implementing this energy saving mechanism, and it is quantified in section III-B through a performance assessment achieved from some different real mobility traces.
Basically sections III-A and III-B describe PROS and CONS of

[1] From Android 4.0 on, the time update via NTP (or NITZ) is implemented natively by the service "Network Time Update". In addition, by analyzing the source code of Android, we can see that the resync is performed every 24 hours. https://github.com/android

the proposed on-off duty cycle solution for understanding the natural (although mobility model dependent) emerging trade-off and properly tuning the system parameters T_{on} and T_{off}. Finally, while implementing the proposed solution on real mobile phones, we noticed that the duration of the battery heavily depends not only from the system parameters T_{on} and T_{off} but also from the implementation strategy. We present these results in III-C.

A. *Measurement of improvements in energy efficiency*

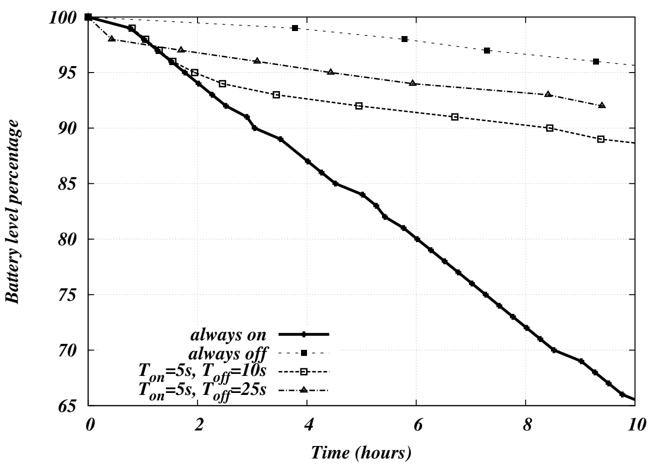

Fig. 4. Battery drain process while keeping the wireless interface always on, always off, or modulating between T_{on}=5s, T_{off}=5s, T_{on}=5s, T_{off}=10s and T_{on}=5s, T_{off}=25s

We evaluated the battery drain on an Android Samsung Galaxy SII mobile phone. All the measurements are performed as follows: a custom *app* periodically logs the battery status and periodically turns on and off the WiFi interface that is configured in ad-hoc mode and used to send an UDP packet each second. The phone is in standby mode without any power lock acquired (neither on CPU or on the WiFi interface) and with the screen turned off. We conservatively set the T_{on} time to 5s that is enough to guarantee an overlap time between the ON periods of two terminal at the net of their clock skew (quantified in sec. II).

Figure 4 presents the preliminary results of the battery duration for the following cases: i) **always on**: the WiFi radio interface is kept always on. This is our reference lower bound for the battery duration time. ii) **always off**: the WiFi radio interface is kept always off. This is our reference upper bound for the battery duration time. iii) T_{on}**,** T_{off}: there is a dedicated thread that periodically turn on the WiFi radio interface for T_{on} seconds and off for T_{off} seconds.

As we can see, even a high duty cycle of 0.33 (T_{off}=10s) provides 25% of residual charge of battery after 10 hours of measurement. Moreover if we decrease the duty cycle up to 0.17 (T_{off}=25s), the residual charge of battery increases up to 32%, that corresponds to a loss of only 4% with respect to the *always off* case.

B. *Analysis of the missing encounter probability*

To properly understand the missed encounter probability that arise from the periodic turning off the WiFi interface, we used some real mobility traces.

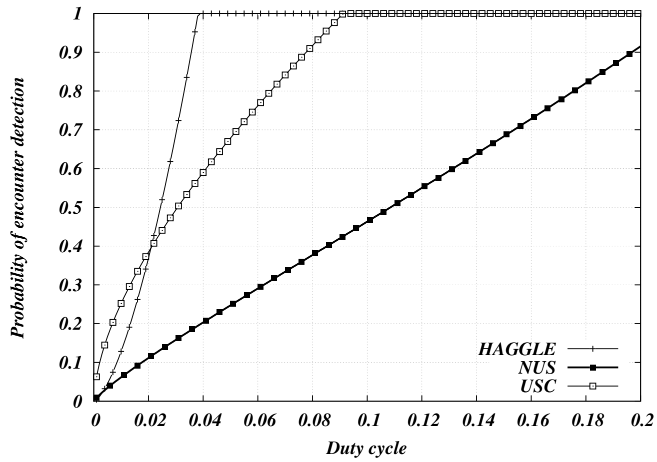

Fig. 5. Probability to detect an encounter versus the duty cycle $\frac{T_{on}}{T_{on}+T_{off}}$, varying the mobility model. T_{on} is setted to 5 seconds.

Unfortunately the great part of the trace that we found in literature has a granularity that is too coarse for our purposes, for instance, [8] has a granularity of the scan of 5 minutes, and [15] performs a Bluetooth scan every 120s. This is often a consequence of the particular measurement technique used, that typically consists in logging the results of periodic Bluetooth scanning on a set of hand-held devices. This problem has been tackled in [16] and overcome by using a different method to record the encounters, based no more on Bluetooth but on 802.15.4 sensors.

However it is well known that the cumulative distribution of the contact duration times approximately follows a power law distribution whose exponent k hardly depends from the scenario we are considering: for instance the fitting that the author themselves found in the Haggle IMote trace [15] is $k = 1.5$, in NUS data [10] $k = 0.84$, while for USC data [16] we have $k = 0.6$. Hence, for the traces we considered, Tte resulting cumulative distribution function of the contact duration is $F_X(t) = max(1 - at^{-k}, 0)$ where k is provided, t is expressed in minutes and a is estimated by curve fitting (for HAGGLE $a = 3.043$, for NUS $a = 0.364$ and for USC $a = 0.894$).

In figure 5 we show the probability of effectively detect an encounter, while we are turning on and off the WiFi radio interface. As we can see, the probability is heavily influenced by the specific human mobility scenario that we are considering. However, for all the considered cases, for values of $T_{off} < 25s$ (that in turn result to duty cycles greater than 0.16) we have that the probability of missing encounter detection is less than 25%, while for $T_{off} < 15s$ we have a loss probability that is minor than 1%.

C. *Implementation aspects*

While developing of the app for the on off behaviour, we noticed that the implementation strategy dramatically impacts the power consumption. For instance, there are several ways to turning on and off the WiFi radio interfaces such as by mounting/unmounting the wireless driver or setting the transmission power to 0mW during the OFF period. The former method saves more energy but it is less responsive requiring long system time (some seconds) to mount/unmount the driver, so that it is not suitable for fast switch. Given that it provides the better performance, in all the results presented in the previous sections we used the mounting/dismounting strategy.

To implement the on off behavior in the Android OS, we explored two different strategies: i) a standard Java Thread that turns on and off the radio interface sleeping in the meanwhile; ii) a Runnable directly scheduled by the Android OS with the *postAtTime* API. In Figure 6 we plot the battery consumption obtained for very frequent modulation ($T_{on} = 500ms$ and $T_{off} = 500ms$) to stress the gap between the two solutions. As we can see, the difference is far from being negligible: the standalone thread approach provides the better performance and thus we used that in all the results presented in the previous sections.

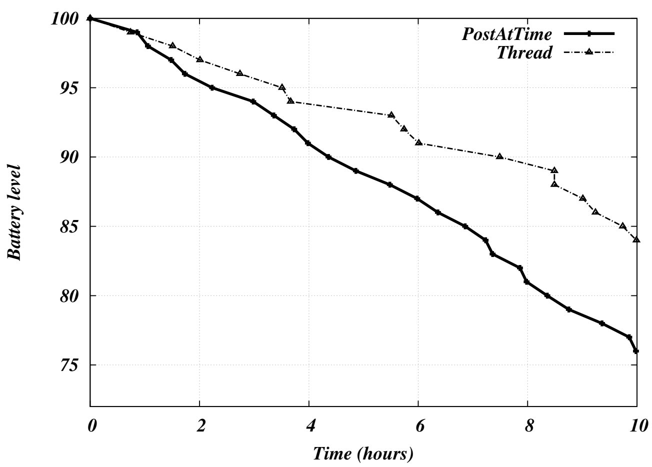

Fig. 6. The battery consumption for the same duty cycle $T_{on} = 500ms$ and $T_{off} = 500ms$ but with different implementation strategies: thread with sleep and *postAtTime* Android API.

IV. Related work

Energy Saving in Opportunistic Network

The typical research works on energy saving in opportunistic networks concern the optimization of the forwarding strategy. The probing interval between two consecutive search procedures can be optimized with respect to the lost transmission opportunities according to specific analytical models [4], [6].

The WiFi-Bluetooth debate

The mobile opp-net are based on local wireless technologies commonly available on the smartphone, thus the selection is restricted to WiFi and Bluetooth technologies. The debate between WiFi and Bluetooth is addressed in the opp-net literature and a survey is reported in [7]. Many works including [7] and [17] present the advantages and disadvantages of both the solutions, concluding that although the Bluetooth technology presents many limitations the high energy consumption of WiFi makes it practically unusable for real applications.

WiFi for Opportunistic networks

As reported, many papers discard WiFi because it consumes a lot. The energy consumption of WiFi have been studied in various works such as [18], [19] and [20]. However, some works have continued to study the application of this technology to opportunistic networks [21]. For instance, WiFi-Opp [22] is an opportunistic communication system that uses WiFi infra-structured mode to create a peer-to-peer network among smartphones because many terminals do not naively support the IEEE802.11 IBSS (WiFi adhoc mode). The paper also evaluate the energy consumption of the system with respect to the WiFi adhoc mode reference case considering various system configurations and using a model base on the real traces.

Some works try to overcame the WiFi energy harvesting using multiple technologies in a hierarchical way: an energy efficient technology is used for node discovery and the WiFi interface is used for the actual communication. An overview of these techniques can be found in [23]. An opportunistic system based on WiFi is presented in [5]: a overall system architecture is presented and a special attention is devoted to the peer-to-peer discovery procedure, in which they introduce many energy efficient optimization. Clearly the proposed technique can be effectively adapted to the on-off scheme proposed in this paper.

On-Off scheduling

Schemes for energy savings based on duty-cycling approaches have been proposed and deeply studied in wireless sensor networks (WSN) [24]. Since usually the WSN nodes are fixed, the main interest in this WSN papers concern the overall message transfer delay introduced by the on/off pattern [25]: they showed that the simple “scheduled rendezvous” approach (in which all nodes wake up simultaneously) is a sub-optimal solution for WSN and that the optimal pattern clearly depends on the network topology. On the contrary, in a opp-net, we need to maximize the discovering probability among mobile nodes and this can only be achieved with a global scheduled rendezvous approach.

A very recent paper proposes an adaptive duty cycle for opportunistic network based on a cooperative approach and protocol to schedule the node wake up intervals [26].

V. Conclusions

In this paper we presented an energy saving solution for opportunistic and delay tolerant networks. The devised approach provides intermittent (but synchronized) WiFi communication across opportunistically connected devices, by introducing a duty cycle so that every device periodically activate/deactivate its wireless radio interfaces. This, along with a global loose synchronization of all the phones, allows them to communicate each other during the ON periods, T_{on} and to increase the battery duration by switching off the radio interface during the OFF periods T_{off}. The price to pay is that contacts between nodes could be missed, resulting in a reduction of transmission opportunities.

Using mobility traces we investigated the amount of such missed contacts varying the duty cycle, together with the benefits we obtain in terms of battery duration. Our measurements campaign indicates that a duty cycle of 0.17 after 10 hours of measurement results in a reduction of the battery level of only the 6% with respect to the always off case, while loosing less than the 25% of contact opportunities according to the considered mobility traces. A study on the clock drift justifies a T_{on} of about 5s to keep the phones synchronized using the default NTP based protocol every 24 hours.

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