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AN UPLINK POWER CONTROL ROUTINE FOR QUALITY-OF-SERVICE EQUALIZATION IN WIRELESS DATA TRANSFER NETWORKS CONSTRAINED TO EQUIDISTANT POWER LEVELS

Background. Power control is a process of adjusting transmitter power output in a communication system to achieve satisfactory performance within the system. In wireless data transfer networks, this process refers to uplink connection, when information about the transmitter power output is sent to the base station, whereupon the power is adjusted in accordance with one or more transmit power control commands received in the downlink. The uplink power control is intended to ensure quality of service declared by the system provider including maintaining a sufficient signal-to-noise ratio and link data rate, reducing interference, overloading, and preserving the battery life.

Objective. Whereas the sum of power levels is constrained to the grand total of the powers transmitted in the uplink of all the transmitters, the quality-of-service equalization is a fundamental task. Henceforward, for a set of equidistant power levels, the goal is to achieve the quality-of-service equalization by non-decreasing powers when moving away from the base station with using the distances from the mobiles to the base station. Inasmuch as the uplink power grand total is “allowed”, the sum of all the powers should be as much as closer to the grand total.

Methods. Principally, ratios of distances to the base station are calculated using an initial value of the path loss exponent. Then the case of the overloaded network is checked out. After that, the base station power responses are calculated using the ratios and the principle of the equal quality of service, wherein the received uplink power should be closely the same for all the users by every uplink transmission. If the farthest/closest transmitters’ powers are out of the power range, they are set down/up to the proper maximum/minimum. The path loss exponent is decreased if the proper maximum is re-violated. Finally, the base station power responses are rounded to values within a set of power levels.

Results. The suggested algorithm deals with powers in watts fitting wireless data transfer networks working in shallow areas (like Wi-Fi, Bluetooth, etc.), for which the number of power levels is relatively great and the range of active uplink transmission powers is relatively narrow. The routine which implements the algorithm still can be optimized depending on the programming environment and paradigm. For instance, C++ and Python will fit for speeding up the performance. Nevertheless, the routine would not sustain the UMTS update frequency, unless a network works with a few tens of users.

Conclusions. The uplink power control routine stated with the six algorithmic items effectively equalizes quality of service in shallow wireless data transfer networks, where user uplink powers are constrained to equidistant power levels in watts. It is not a one-step but a multi-step process during which four types of conditions are successively tried to get satisfied. Eventually, the factual sum of all the powers transmitted in the uplink may become “harmlessly” less than the grand total.

Keywords: wireless data transfer network; equal quality of service; uplink power control; distances to the base station; power levels; path loss exponent; dichotomization.

Introduction

Power control is a process of adjusting transmitter power output in a communication system to achieve satisfactory performance within the system. In wireless data transfer networks, this process refers to uplink connection, when information about the transmitter power output is sent to the base station (mobile-to-base), whereupon the power is adjusted in accordance with one or more transmit power control commands received in the downlink (which follows the uplink) [1, 2]. The uplink power control is intended to ensure quality of service declared by the system provider [3, 4]. This also includes maintaining a sufficient signal-to-noise

ratio and link data rate, reducing interference, overloading, and preserving the battery life [5].

One of the most important aspects of the quality-of-service principle is ensuring equal access for all the users. Along with that, reducing interference relates to effective spectrum management [6, 7]. The latter is very important for overall wireless communications, which have been growing dramatically. All these items are thoroughly intertwined influencing each other. Thus, ensuring quality-of-service equalization additionally helps to sustain the increasing transmission of radio waves, which threatens not only with interference, but also with plausible health issues [8].

In general, the base station manages a definite set of power levels of the transmitters/mobiles linked to it. This is the centralized power control [6]. Obviously, the performance of the base station cannot be compromised by high power local mobiles which may tend to mask out weaker mobiles farther away from the base station. Therefore, transmit power output of the nearer mobiles is decreased, whereas the farther mobiles are adjusted to have higher transmit power outputs [8, 9].

For instance, a table of GSM power levels is defined, and the base station controls the power of the mobile by sending a GSM “power level” number/tag/identifier. The mobile then adjusts its power by an appropriate accuracy: at the maximum power levels it is typically ± 2 dB, whereas this relaxes to ± 5 dB at the lower levels. The power level numbers vary according to the GSM band in use [3, 4]:

1) the power level table for GSM 900 has 18 power levels – from 2 to 19, which correspond to power output levels from 39 dBm (7.94 W) down to 5 dBm (3.2 mW) with a step of 2 dBm;

2) the power level table for GSM 1800 has 19 power levels – 29, 30, 31, 0, 1, 2, ..., 13, 14, 15, which correspond to power output levels from 36 dBm (3.98 W) down to 0 dBm (1 mW) with a step of 2 dBm;

3) the power level table for GSM 1900 has 18 power levels – 30, 31, 0, 1, 2, 3, ..., 13, 14, 15, which correspond to power output levels (in dBm) 33, 32, 30, 28, 26, 24, ..., 4, 2, 0 (in milliwatts: 2000, 1585, 1000, 631, 398, 251, ..., 2.5, 1.6, 1).

The UMTS uses its own conception of uplink power control [1, 2, 6]. The transmitter is capable of changing the output power with a step size of 1, 2, and 3 dB depending on a set of transmit power control commands. Thus, once the set is for “down”/“up” within the most accurate power control range, the transmit power is reduced/increased by 1 dB; otherwise the transmit power is not changed.

The main problem in such a power adjustment is that it is too slow. Indeed, GSM cellular systems has their update frequency of 2 Hz. The UMTS updates powers at 1500 Hz, but it reacts against weaker or stronger signal (received by the base station) only with a single step, so abrupt changes of signal power are impossible to compensate [6, 10].

Contrary to the centralized power control, mobiles can be allowed to update their powers autonomously, considering quality of service they perceive [8]. As the mobiles become independent of the base station, they can be considered as selfish agents (players) who try to maximize their utilities

(i. e., throughput and connectivity) [6]. Then methods of decision-making theory are applicable. Thus, non-cooperative game theory models of wireless network power control claim that the selfish mobiles maximizing their own utility are opposed to maximizing the overall performance of the wireless data transfer network, in which the mobiles operate [6, 7]. Then, with a utility function assigned for each mobile, the most stable and advantageous situation in the game is determined. However, substantiation of the utility function relies only on distances from the mobiles to the base station, rather than distances between each pair of mobiles [6]. This does not improve measuring interference if to compare the game theory approach to both the table-of-power-levels and one-step-adjustment approaches mentioned above. Besides, re-calculation of the power according to the most favorable situation becomes exponentially slow when the number of mobiles operating simultaneously linearly increases.

Problem statement

Whereas the sum of power levels is constrained to the grand total of the powers transmitted in the uplink off all the transmitters, the quality-of-service equalization is a fundamental task [1, 2, 7, 9, 11]. Power levels can be equidistant like in GSM tables, but their selection might be driven by distances from the mobiles to the base station. These distances are estimated by a GPS navigation technique, which is presumed to be used in the game theory approach as well. Henceforward, for a set of equidistant power levels, the goal is to achieve the quality-of-service equalization by non-decreasing powers when moving away from the base station with using the distances. Inasmuch as the uplink power grand total is “allowed”, the sum of all the powers should be as much as closer to the grand total.

Parameters used for uplink power control

A number of active transmitters N is determined automatically. So, there are seven types of parameters used for uplink power control. Some of these parameters are defined by the system, the rest of them are measured.

The system-defined parameters are:

1. An initial (nominal) value of the path loss exponent μ . Values of exponent μ are normally in the range of 2 to 4, where μ becomes greater for propagation of radio waves in relatively lossy environments. The path loss exponent can reach values

in the range of 4 to 6 in covered environments (buildings, basements, sport-arenas, etc.). As the time goes by (say, in years), μ can be increased if the area where a base station operates becomes over-built with various architectural constructions.

2. A maximum-tolerated grand total p_{Σ} of the powers transmitted in the uplink off all the transmitters (either in dBm or watts). Value p_{Σ} depends on the capacity of the network. Occasionally, p_{Σ} can be expressed as a maximal number of user transmitters which could effectively simultaneously work within a scope of the same base station.

3. A maximally possible transmitter power output p_{\max} (either in dBm or watts).

4. A minimally possible transmitter power output p_0 (either in dBm or watts).

5. A set of uplink power levels $G = \{\bar{p}_l\}_{l=1}^L$, where $\bar{p}_1 = p_0$ and $\bar{p}_L = p_{\max}$. As these L levels are assumed to be equidistant,

$$\bar{p}_l = p_0 + (l - 1) \cdot \frac{p_{\max} - p_0}{L - 1} \quad \forall l = \overline{1, L}. \quad (1)$$

The measured parameters are:

1. Powers $\{p_k\}_{k=1}^N$ transmitted in the uplink.

They are measured by user transmitters themselves. Then they are sent to the base station in the nearest uplink transmission.

2. Distances $\{d_k\}_{k=1}^N$ to the base station. They are estimated by a GPS navigation technique. They are sent to the base station along with powers $\{p_k\}_{k=1}^N$. Thus, each transmitter sends a pair of its current power and distance. The said current power is to be considered as a request for the next uplink transmission.

For further processing, distances $\{d_k\}_{k=1}^N$ are sorted automatically by the base station in descending order:

$$d_i \geq d_{i+1} \quad \forall i = \overline{1, N - 1}. \quad (2)$$

Thus, the closest transmitter has the greatest index, and the farthest transmitter has index 1. Obviously, powers $\{p_k\}_{k=1}^N$ are not sorted.

Ratios of distances to the base station

The reduction in power density of radio waves as they propagate through space is called path loss. Path loss is a major component in the analysis and

design of the link budget of a wireless data transfer network. If a transmitter is distanced by d meters from a receiver, then the path loss in the simplified form is estimated in dB as

$$H = 10\mu \lg d, \quad (3)$$

where system losses are included into the path loss exponent. If a transmitted power is p_{transmit} , and the received power is p_{rec} , then path loss (3) can be re-written as

$$H = 10\mu \lg d = 10 \lg \frac{p_{\text{transmit}}}{p_{\text{rec}}},$$

whence

$$\lg d^\mu = \lg \frac{p_{\text{transmit}}}{p_{\text{rec}}}, \quad d^\mu = \frac{p_{\text{transmit}}}{p_{\text{rec}}},$$

and the power received at the base station is

$$p_{\text{rec}} = \frac{p_{\text{transmit}}}{d^\mu}. \quad (4)$$

Hence, quality of service can be equalized by taking into account factor d^μ in (4) for each pair of active transmitters. This is why ratios of distances

$$r_{i,i+1} = \frac{d_i^\mu}{d_{i+1}^\mu} \quad \forall i = \overline{1, N - 1} \quad (5)$$

by the path loss model (3) will be used further. Ratios (5) are calculated by the base station, which is assumed to “know” the path loss exponent over the area wherein this station operates.

User power requests and base station power responses

The base station is tasked to map power requests $\{p_k\}_{k=1}^N$ in every uplink into powers $\{p_k^*\}_{k=1}^N$ corrected so, that quality-of-service equalization could be ensured as accurately as possible. Values $\{p_k^*\}_{k=1}^N$ are factual base station power responses. When the base station receives power requests $\{p_k\}_{k=1}^N$, it checks whether they not exceed the maximum-tolerated grand total by the power descending order, i. e.

$$\sum_{k=1}^N p_k \leq p_{\Sigma} \quad (6)$$

by

$$p_i \geq p_{i+1} \quad \forall i = \overline{1, N - 1}. \quad (7)$$

Descending order (7) is necessary due to (2) and (4). If (6) and (7) hold then the powers are not corrected:

$$p_k^* = p_k \quad \forall k = \overline{1, N}. \quad (8)$$

Otherwise, they are corrected so, that

$$\sum_{k=1}^N p_k^* \leq p_\Sigma \quad (9)$$

by

$$p_k^* \leq p_{\max} \quad \forall k = \overline{1, N} \quad (10)$$

and

$$p_0 \leq p_k^* \quad \forall k = \overline{1, N}. \quad (11)$$

Meanwhile, the difference

$$p_\Sigma - \sum_{k=1}^N p_k^* \quad (12)$$

by (9) should be minimized. In particular, the marginal case

$$\sum_{k=1}^N p_k^* = p_\Sigma \quad (13)$$

in (9) is plausible and acceptable.

A case of the overloaded network

If, occasionally,

$$Np_0 > p_\Sigma \quad (14)$$

holds, then the farthest-from-the-base-station

$$N_{\text{off}} = N - \xi\left(\frac{p_\Sigma}{p_0}\right) \quad (15)$$

transmitters whose distances are $\{d_w\}_{w=1}^{N_{\text{off}}}$, where function $\xi(x)$ returns the integer part of x , will be turned off:

$$p_w^* = 0 \quad \forall w = \overline{1, N_{\text{off}}} \text{ by } N_{\text{off}} < N. \quad (16)$$

This is done so because those N_{off} transmitters would overload the network. Then

$$N^{(\text{obs})} = N \text{ and } N = \xi\left(\frac{p_\Sigma}{p_0}\right), \quad (17)$$

and only power requests $\{p_l\}_{l=N_{\text{off}}+1}^{N^{(\text{obs})}}$ are going to be considered as (after the respective re-indexing under

the updated N) “new” $\{p_k\}_{k=1}^N$ by distances

$\{d_l\}_{l=N_{\text{off}}+1}^{N^{(\text{obs})}}$ considered similarly as “new” $\{d_k\}_{k=1}^N$.

Those N_{off} farthest-from-the-base-station transmitters will receive a command in the following downlink to turn off. Nevertheless, such a turn-off is not permanent. The turned-off transmitter becomes inactive just for a period of a single update (e. g., for 1/1500 s in the UMTS). After that, it is likely the transmitter will start searching for another network, if the current network continues disconnecting it by sending “zero” power responses (16).

Raw calculation of the base station power responses

Ensuring the equal quality of service implies an equal received uplink power for all the users by every uplink transmission. This means that, for the neighboring transmitters,

$$p_{\text{rec}} = \frac{p_{i+1}^*}{d_{i+1}^\mu} = \frac{p_i^*}{d_i^\mu} \quad \forall i = \overline{1, N-1}. \quad (18)$$

It follows from (18) that the uplink power of i -th transmitter should be set at

$$p_i^* = \frac{p_{i+1}^* d_i^\mu}{d_{i+1}^\mu} = r_{i,i+1} p_{i+1}^* \quad \forall i = \overline{1, N-1}. \quad (19)$$

Obviously,

$$p_N^* = \lambda p_N \text{ by some } \lambda > 0. \quad (20)$$

Then power of every farther transmitter is expressed by the closest one with (20):

$$p_{N-1}^* = r_{N-1,N} p_N^* = r_{N-1,N} \lambda p_N,$$

$$p_{N-2}^* = r_{N-2,N-1} p_{N-1}^* = r_{N-2,N-1} r_{N-1,N} \lambda p_N,$$

and so on, including the power for the farthest transmitter

$$p_1^* = r_{12} p_2^* = r_{12} r_{23} p_3^* = \dots = \left(\prod_{s=1}^{N-1} r_{s,s+1} \right) \lambda p_N.$$

Therefore,

$$p_k^* = \left(\prod_{s=k}^{N-1} r_{s,s+1} \right) \lambda p_N \quad \forall k = \overline{1, N-1}. \quad (21)$$

Then, using marginal case (13) and the-closest-transmitter expression (21),

$$\begin{aligned} \sum_{k=1}^N p_k^* &= \lambda p_N + \sum_{k=1}^{N-1} \left(\prod_{s=k}^{N-1} r_{s,s+1} \right) \lambda p_N \\ &= \lambda p_N \left(1 + \sum_{k=1}^{N-1} \left(\prod_{s=k}^{N-1} r_{s,s+1} \right) \right) = p_{\Sigma}. \end{aligned} \quad (22)$$

So, the nominally appropriate uplink power of the closest transmitter is

$$p_N^* = \lambda p_N = \frac{p_{\Sigma}}{1 + \sum_{k=1}^{N-1} \left(\prod_{s=k}^{N-1} r_{s,s+1} \right)}, \quad (23)$$

and nominally appropriate uplink powers of the remaining transmitters are

$$p_j^* = \frac{p_{\Sigma} \prod_{s=j}^{N-1} r_{s,s+1}}{1 + \sum_{k=1}^{N-1} \left(\prod_{s=k}^{N-1} r_{s,s+1} \right)} \quad \forall j = \overline{1, N-1}. \quad (24)$$

Note that uplink powers by (23) and (24) called nominally appropriate due to formulae (23) and (24) cannot give

$$p_k^* \in G = \{\bar{p}_j\}_{j=1}^L \quad \forall k = \overline{1, N} \quad (25)$$

at once. Condition (25) is necessary for finally setting the uplink powers.

Setting down/up to the proper maximum/minimum

When a cycle of the raw calculation of the base station power responses is completed, there is a subtask to check whether conditions (10) and (11) are not violated. If

$$p_v^* > p_{\max} \quad \forall v = \overline{1, N_{\text{over}}} \quad \text{by } 0 < N_{\text{over}} < N, \quad (26)$$

then (10) is violated, and response powers of those N_{over} farthest-from-the-base-station transmitters are set down (currently, not finally) at the proper maximum:

$$p_v^* = p_{\max} \quad \forall v = \overline{1, N_{\text{over}}} \quad \text{by } 0 < N_{\text{over}} < N. \quad (27)$$

Subsequently, the remaining powers, which are $\{p_k^*\}_{k=N_{\text{over}}+1}^N$ with their respective distances $\{d_k\}_{k=N_{\text{over}}+1}^N$, are corrected once again with using (23) and (24) by

$$p_{\Sigma}^{(\text{obs})} = p_{\Sigma}, \quad p_{\Sigma} = p_{\Sigma}^{(\text{obs})} - p_{\max} N_{\text{over}}. \quad (28)$$

If

$$\begin{aligned} p_u^* < p_0 \quad \forall u = \overline{N - N_{\text{under}} + 1, N} \\ \text{by } 0 < N_{\text{under}} < N, \end{aligned} \quad (29)$$

then (11) is violated, and response powers of those N_{under} closest-to-the-base-station transmitters are set up (currently, not finally) at the proper minimum:

$$\begin{aligned} p_u^* = p_0 \quad \forall u = \overline{N - N_{\text{under}} + 1, N} \\ \text{by } 0 < N_{\text{under}} < N. \end{aligned} \quad (30)$$

Subsequently, the remaining powers, which are $\{p_k^*\}_{k=1}^{N-N_{\text{under}}}$ with their respective distances $\{d_k\}_{k=1}^{N-N_{\text{under}}}$, are corrected once again with using (23) and (24) by

$$p_{\Sigma}^{(\text{obs})} = p_{\Sigma}, \quad p_{\Sigma} = p_{\Sigma}^{(\text{obs})} - p_0 N_{\text{under}}. \quad (31)$$

Theoretically, both cases (26) and (29) are possible. The case with rectifying situation (29) always follows the case with rectifying situation (26). However, even after having re-corrected powers by (31), there still can be a violation (re-violation) of condition (10). Then the path loss exponent is adjusted “manually”.

Adjusting the path loss exponent

If (10) is re-violated after having rectified situation (29), the path loss exponent, despite the real losses in the surrounding environment, is decreased “manually”. It is a subtask wherein the path loss exponent must be minimally decreased down to value μ^* such, that conditions (10) and (11) hold both at this value. In fact, μ^* will become a maximally possible value of the path loss exponent, at which conditions (10) and (11) hold both.

Firstly,

$$\mu_{\text{upper}} = \mu \quad \text{and} \quad \mu_{\text{lower}} = \mu. \quad (32)$$

Secondly, for some $\Delta\mu_{\text{dec}} > 0$ a mini-procedure

$$\mu_{\text{lower}}^{(\text{obs})} = \mu_{\text{lower}} \quad \text{and} \quad \mu_{\text{lower}} = \mu_{\text{lower}}^{(\text{obs})} - \Delta\mu_{\text{dec}} \quad (33)$$

is executed until (10) and (11) hold both. This is a primal rough stage of determining the interval $(\mu_{\text{lower}}; \mu_{\text{upper}})$ within which the unknown μ^* is

enclosed. Thirdly, a procedure of decreasing gradually the path loss exponent is executed until the decrement becomes too small. Thus,

$$\Delta\mu = \frac{\mu_{\text{upper}} - \mu_{\text{lower}}}{2} \quad (34)$$

is calculated and a new path loss exponent is

$$\mu = \mu_{\text{lower}} + \Delta\mu. \quad (35)$$

The powers are re-corrected again and

$$\Delta\mu^{(\text{obs})} = \Delta\mu, \quad \Delta\mu = \Delta\mu^{(\text{obs})} / 2. \quad (36)$$

If (10) is still violated then

$$\mu^{(\text{obs})} = \mu \quad \text{and} \quad \mu = \mu^{(\text{obs})} - \Delta\mu, \quad (37)$$

otherwise

$$\mu^{(\text{obs})} = \mu \quad \text{and} \quad \mu = \mu^{(\text{obs})} + \Delta\mu. \quad (38)$$

The sequence of assignments (36) and either (37) or (38) is repeated while $\Delta\mu > \varepsilon$, where ε is an insignificant change (either decrement or increment) of the path loss exponent.

Uplink power control with equidistant power levels

After the raw calculation of the base station power responses is complete and conditions (10) and (11) hold both by marginal case (13), a power control algorithm pulls the powers to condition (25). For this, a step

$$\Delta p = \frac{p_{\text{max}} - p_0}{L - 1} \quad (39)$$

of set $G = \{\bar{p}_l\}_{l=1}^L$ of the L power levels is used. If powers $\{p_k^*\}_{k=1}^N$ do not satisfy condition (25), they should be rounded to values within set $G = \{\bar{p}_l\}_{l=1}^L$. Firstly, remainders

$$\rho_k = (p_k^* - p_0) - \Delta p \xi \left(\frac{p_k^* - p_0}{\Delta p} \right) \quad \forall k = \overline{1, N} \quad (40)$$

are calculated and the powers are rounded to fit set $G = \{\bar{p}_l\}_{l=1}^L$:

$$p_k^{*(\text{obs})} = p_k^*, \quad p_k^* = p_k^{*(\text{obs})} - \rho_k. \quad (41)$$

Secondly, a set I_+ of indices is found, for which

$$\rho_{i_+} > \frac{\Delta p}{2} \quad \forall i_+ \in I_+, \quad (42)$$

whereupon

$$p_{i_+}^{*(\text{obs})} = p_{i_+}^*, \quad p_{i_+}^* = p_{i_+}^{*(\text{obs})} + \Delta p \quad \forall i_+ \in I_+. \quad (43)$$

Thirdly, a set I_0 of indices is found, for which

$$p_k^* > p_0 \quad \forall i_0 \in I_0. \quad (44)$$

If $I_0 = \emptyset$ then condition (25) is trivially true, and the requests

$$\{p_k^*\}_{k=1}^N = \{p_0\}_{k=1}^N \quad (45)$$

are returned to the following downlink transmission; otherwise,

$$I_0 = \{q\}_{q=1}^Q \quad \text{and} \quad i_- = Q = |I_0|. \quad (46)$$

Then, while (9) is violated, the following mini-procedure is executed:

$$p_{i_-}^{*(\text{obs})} = p_{i_-}^*, \quad p_{i_-}^* = p_{i_-}^{*(\text{obs})} - \Delta p, \quad (47)$$

and

$$i_-^{(\text{obs})} = i_-, \quad i_- = i_-^{(\text{obs})} - 1. \quad (48)$$

Obviously, subroutine with (40)–(48) is executed only for those transmitters who are active (i. e., are not turned off due to the overloaded network).

Uplink power control routine for quality-of-service equalization

Basically, this is a multi-step routine based on the stated above in the successive order. The routine is formed by the following algorithm:

1. Ratios of distances to the base station are calculated by (5).
2. The case of the overloaded network is checked out using (14)–(17).
3. Raw calculation of the base station power responses is executed by (23) and (24).
4. Setting down/up to the proper maximum/minimum is executed, if required, by using (26)–(31).
5. The path loss exponent is decreased using (32)–(38) if (10) is re-violated.
6. The base station power responses are rounded to values within set $G = \{\bar{p}_l\}_{l=1}^L$ by using (39)–(48).

It can be successfully implemented in C++, Python, or similar environments, without any

special requirements. The single bottleneck is in those iterations occurring after the raw calculation.

Examples of the uplink power control routine application

For exemplifying the uplink power control routine application, let $\mu = 4$ as it normally is for areas with city buildings and constructions. Note that powers are in watts. Fig. 1 shows a location example of 800 active users (transmitters) with sufficiently great range of uplink powers and their levels. The uplink powers are corrected according to Fig. 2. A result of some limitations to the network is hardly

seen in Fig. 3, but it is well seen in the corresponding Fig. 4. A location example with turning the farthest users (transmitters) off is in Fig. 5, whereupon Fig. 6 shows a trivial distribution of grand total of the powers transmitted in the uplink.

Those illustrations are much simplified but they give a general imagination of what results of the routine application are expected. Another important property is the time performance, which is better for cases like that in Fig. 6 (the result in Fig. 6 is obtained in about 25 times faster than that in Fig. 4). By the way, increasing the number of power levels does not retard the time of the routine execution.

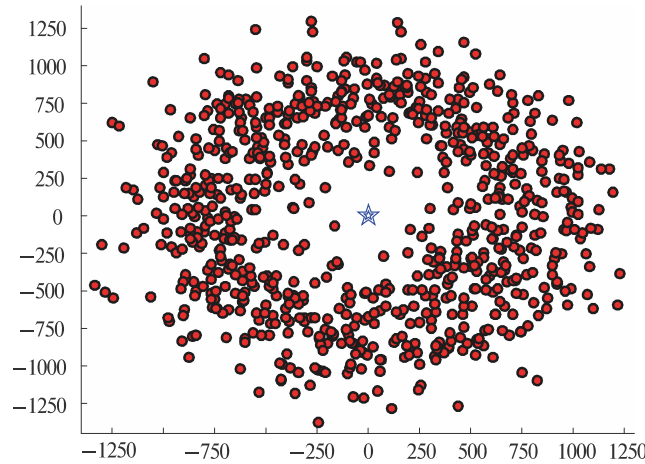


Fig. 1. A location example of 800 active users (transmitters) by $p_{\Sigma} = 64$, $p_{\max} = 0.2$, $p_0 = 0.001$, $L = 200$ (distances to the base station which is at the origin are in meters)

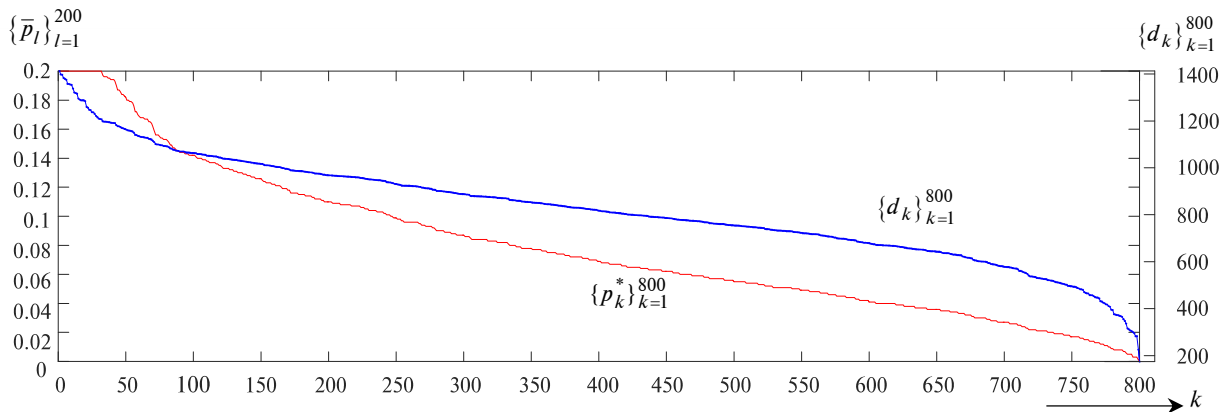


Fig. 2. Power responses by 200 power levels to transmitters in Fig. 1

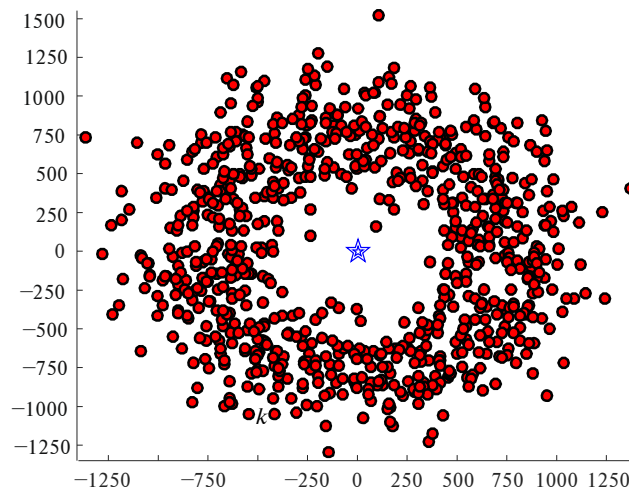


Fig. 3. A location example of 800 active users (transmitters) by $p_{\Sigma} = 32$, $p_{\max} = 0.2$, $p_0 = 0.02$, $L = 20$ (distances to the base station which is at the origin are in meters)

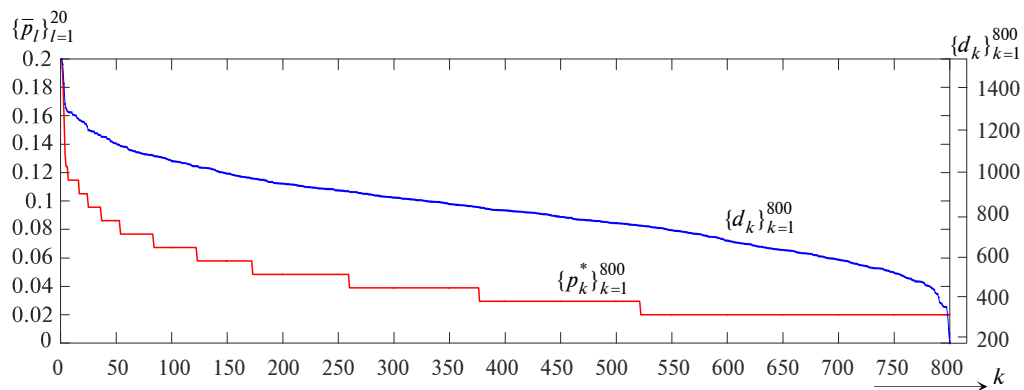


Fig. 4. Power responses by 20 power levels to transmitters in Fig. 3

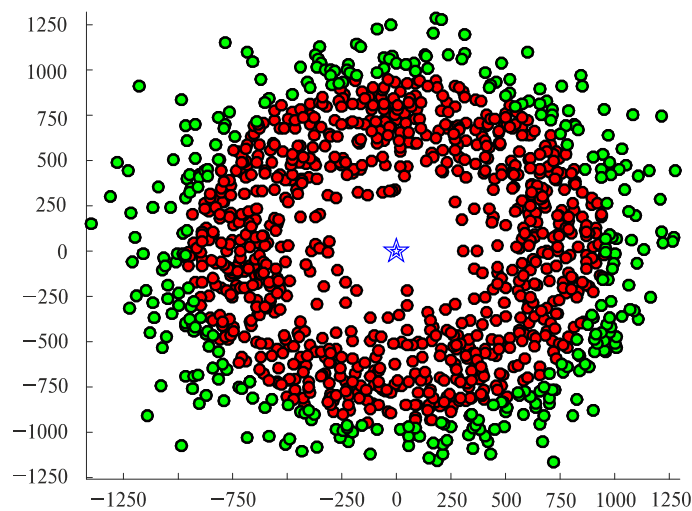


Fig. 5. A location example of 1217 users (transmitters), among which 327 are currently turned off (highlighted with the different color) by $p_{\Sigma} = 17.8$, $p_{\max} = 0.2$, $p_0 = 0.02$, $L = 20$ (distances to the base station which is at the origin are in meters)

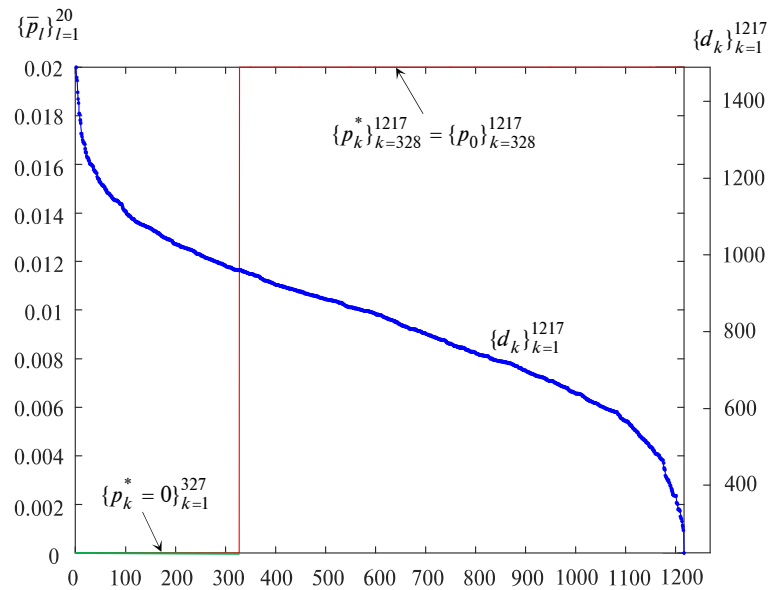


Fig. 6. Power responses and turn-offs by 20 power levels to transmitters in Fig. 5

Discussion

The suggested algorithm is directed to work with powers in watts. A transition to decibel-milliwatts can be done but it is not worth for wireless data transfer networks working in shallow areas (like Wi-Fi, Bluetooth, etc.), for which the number of power levels is relatively great and the range of active uplink transmission powers is relatively narrow. The routine which implements the algorithm still can be optimized depending on the programming environment and paradigm. For instance, C++ and Python will fit for speeding up the performance.

Nevertheless, the routine would not sustain the UMTS update frequency. Experiments show that it takes no shorter than 0.5 to a few milliseconds for correcting the power requests within a network with a few hundreds currently active users. However, networks with a few tens of users process their power requests much faster (no longer than 0.5 ms that fits the UMTS update frequency). Moreover, the routine could be sped up by an appropriate implementation of dichotomization [12] by (32)–(38).

An apparent advantage of the uplink power routine is that it is capable to smooth much the

distribution of uplink powers. Increasing the number of power levels seemingly improves the smoothness (compare Fig. 4 to Fig. 2) without significant delays in performance.

Conclusions

The uplink power control routine stated with the six algorithmic items is intended for quality-of-service equalization in wireless data transfer networks, where user uplink powers are constrained to equidistant power levels in watts. The routine is based on calculating ratios of distances to the base station and involving a set of uplink power levels, which allow approximating to the equalization by smoothing uplink powers' distribution. It is not a one-step but a multi-step process during which conditions (13), (10), (11), (25) are successively tried to get satisfied. Eventually, condition (13) may fall out due to power level constraint (25), and condition (9) becomes true. The carried out research can be furthered in order to optimize the time of the routine execution.

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В.В. Романюк

ПРОГРАМА КОНТРОЛЮ ПОТУЖНОСТІ У ВИСХІДНОМУ НАПРЯМКУ ДЛЯ ВИРІВНЮВАННЯ ЯКОСТІ СЕРВІСУ В БЕЗПРОВОДОВИХ МЕРЕЖАХ ПЕРЕДАЧІ ДАНИХ З ОБМЕЖЕННЯМ ДО РІВНОВІДДАЛЕНИХ РІВНІВ ПОТУЖНОСТІ

Проблематика. Контроль потужності є процесом регулювання вихідної потужності передавача в системі зв'язку для досягнення задовільної продуктивності в цій системі. У безпроводових мережах передачі даних цей процес відноситься до висхідної лінії зв'язку, коли інформація про вихідну потужність передавача надсилається на базову станцію, після чого потужність регулюється відповідно до однієї або більше команд керування потужністю передачі, що приймаються у низхідній лінії зв'язку. Керування потужністю висхідної лінії зв'язку призначене для забезпечення якості обслуговування, заявленої системним провайдером, включаючи підтримку достатнього співвідношення сигнал/шум і швидкість передачі даних у з'єднанні, зменшення інтерференції, перевантаження і збереження строку служби батареї.

Мета дослідження. У той час як сума рівнів потужності обмежена загальною сумою потужностей, що передаються у висхідній лінії зв'язку від усіх передавачів, вирівнювання якості обслуговування є фундаментальним завданням. Відтак, маючи набір рівновіддалених рівнів потужності, метою є досягнення вирівнювання якості сервісу за неспадних потужностей при віддаленні від базової станції з використанням відстаней мобільних вузлів до базової станції. Оскільки деяка загальна сума потужності висхідної лінії “дозволена”, сума всіх потужностей повинна бути максимально наближеною до цієї загальної суми.

Методика реалізації. Співвідношення відстаней до базової станції обчислюються з використанням початкового значення показника втрат на трасі. Потім перевіряється випадок перевантаженої мережі. Після цього потужності-відповіді базової станції обчислюються з використанням цих співвідношень і принципу рівної якості обслуговування, причому прийнята потужність висхідної лінії зв'язку повинна бути практично однаковою для всіх користувачів у кожній передачі по висхідній лінії. Якщо потужності найвіддаленіших/найближчих передавачів знаходяться поза діапазоном потужності, вони встановлюються донизу/доверху до відповідного максимуму/мінімуму. Показник втрат на трасі зменшується, якщо відповідний максимум повторно порушується. Нарешті, потужності-відповіді базової станції округлюються до значень у межах деякого набору рівнів потужності.

Результати дослідження. Запропонований алгоритм стосується потужностей у ватах, що підходить безпроводовим мережам передачі даних, які працюють у невеликих районах (наприклад, Wi-Fi, Bluetooth і т.д.), для яких кількість рівнів потужності є відносно великою, а діапазон активних потужностей передачі по висхідній лінії є відносно вузьким. Програма, що реалізує алгоритм, все ще може бути оптимізована залежно від середовища програмування та парадигми. Наприклад, C++ і Python дадуть можливість пришвидшити роботу. Проте ця програма не підтримує частоту оновлення в UMTS, якщо тільки мережа не працює з лише декількома десятками користувачів.

Висновки. Програма контролю потужності висхідної лінії зв'язку, викладена у шести алгоритмічних елементах, ефективно вирівнює якість обслуговування в дрібних безпроводових мережах передачі даних, де потужності висхідної лінії зв'язку обмежені рівновіддаленими рівнями потужності у ватах. Ця програма є не однокроковим, а багатокроковим процесом, під час якого послідовно намагаються задовольнити чотири типи умов. Зрештою, фактична сума всіх потужностей, переданих у висхідній лінії, може стати “нешкідливо” меншою, ніж зазначена загальна сума.

Ключові слова: безпроводова мережа передачі даних; рівна якість обслуговування; контроль потужності висхідної лінії зв'язку; відстані до базової станції; рівні потужності; показник втрат на трасі; дихотомізація.

В.В. Романюк

ПРОГРАММА КОНТРОЛЯ МОЩНОСТИ В ВОСХОДЯЩЕМ НАПРАВЛЕНИИ ДЛЯ ВЫРАВНИВАНИЯ КАЧЕСТВА СЕРВИСА В БЕСПРОВОДНЫХ СЕТЯХ ПЕРЕДАЧИ ДАННЫХ С ОГРАНИЧЕНИЕМ ДО РАВНОУДАЛЕННЫХ УРОВНЕЙ МОЩНОСТИ

Проблематика. Контроль мощности является процессом регулирования выходной мощности передатчика в системе связи для достижения удовлетворительной производительности в этой системе. В беспроводных сетях передачи данных этот процесс относится к восходящей линии связи, когда информация о выходной мощности передатчика направляется на базовую станцию, после чего мощность регулируется в соответствии с одной или более командами управления мощностью передачи, принимаемыми в нисходящей линии связи. Управление мощностью восходящей линии связи предназначено для обеспечения качества обслуживания, заявленного системным провайдером, включая поддержание достаточного отношения сигнал/шум и скорость передачи данных в соединении, уменьшение интерференции, перегрузку и сохранение срока службы батареи.

Цель исследования. В то время как сумма уровней мощности ограничена общей суммой мощностей, передаваемых в восходящей линии связи от всех передатчиков, выравнивание качества обслуживания является фундаментальным заданием. Поэтому, имея набор равноудаленных уровней мощности, целью является достижение выравнивания качества сервиса при неубывающих мощностях при удалении от базовой станции с использованием расстояний мобильных узлов до базовой станции. Поскольку некая общая сумма мощности восходящей линии "разрешена", сумма всех мощностей должна быть максимально приближенной к этой общей сумме.

Методика реализации. Соотношения расстояний до базовой станции вычисляются с использованием исходного значения показателя потерь на трассе. Затем проверяется случай перегруженной сети. После этого мощности-отклики базовой станции вычисляются с использованием этих соотношений и принципа равного качества обслуживания, причем принимаемая мощность восходящей линии связи должна быть практически одинаковой для всех пользователей в каждой передаче по восходящей линии. Если мощности самых удаленных/ближайших передатчиков находятся вне диапазона мощности, они устанавливаются вниз/вверх к соответствующему максимуму/минимуму. Показатель потерь на трассе уменьшается, если соответствующий максимум повторно нарушается. Наконец, мощности-отклики базовой станции округляются до значений в пределах некоторого набора уровней мощности.

Результаты исследования. Предложенный алгоритм относится к мощностям в ваттах, что подходит беспроводным сетям передачи данных, работающим в небольших районах (например, Wi-Fi, Bluetooth и т.д.), для которых количество уровней мощности является относительно большим, а диапазон активных мощностей передачи по восходящей линии является относительно узким. Программа, реализующая алгоритм, все еще может быть оптимизирована в зависимости от среды программирования и парадигмы. Например, C++ и Python позволят ускорить работу. Тем не менее эта программа не поддерживает частоту обновления в UMTS, если только сеть не работает с лишь несколькими десятками пользователей.

Выводы. Программа контроля мощности восходящей линии связи, изложенная в шести алгоритмических элементах, эффективно выравнивает качество обслуживания в мелких беспроводных сетях передачи данных, где мощности восходящей линии связи ограничены равноудаленными уровнями мощности в ваттах. Эта программа является не одношаговым, а многошаговым процессом, во время которого последовательно пытаются удовлетворить четырем типам условий. В конце концов фактическая сумма всех мощностей, передаваемых в восходящей линии, может стать "безвредно" меньшей, чем указанная общая сумма.

Ключевые слова: беспроводная сеть передачи данных; равное качество обслуживания; контроль мощности восходящей линии связи; расстояния до базовой станции; уровни мощности; показатель потерь на трассе; дихотомизация.

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