INFLUENCE OF CONNECTION LENGTH ON SPEECH SIGNAL QUALITY IN PACKET NETWORK OF ELECTRIC POWER UTILITY

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In this paper the quality of speech signal in the packet network of Electric Power Utility is estimated. It is shown that the influence of the (group) packet loss is cumulative, i.e. that the decrease of speech signal quality is proportional to the number of network sites on the speech connection route.

1. INTRODUCTION

Packet networks are substituting classic networks more and more. This substitution also happens in the field of telephone network. The use of packet network for telephone service brings some new factors which can impact the quality of telephone service. These factors haven't existed in classic telephone technics (for example speech signal compressors or packet loss) or had negligible influence (for example, speech signal delay and echo). The new methods for the estimation of the influence of these factors on speech signal quality are developed and are under development (E-model). In this short paper we consider the influence of packet loss on packetized speech signal quality in one special packet network – the packet network of Electric Power Utility (EPU). This network differs from other networks in three important aspects. The first one is that the equipment of network nodes is in the power stations and is under the great influence of power system. The second one originates from the first one: the influence of power system almost always causes burst packet loss. The third one is that the possibility of alternate routing of speech packets in the network in order to achieve the high availability is more used. As opposed to other networks, alternate routing is obligatory in the EPU network and there are more alternate routes. This fact imposes the problem of signal quality equalization between two nodes when
speech packets are transmitted across different routes. Considering all three mentioned facts, the quality of telephone signals must be estimated in different way than in the case of usual packet networks.

After this, introductory, part, the structure of the packet network of EPU is presented in section 2. The characteristic of this network is the appearance of overvoltage disturbances at each power site. These disturbances cause packet loss as explained in this section.

The E-model for the estimation of speech signal quality is presented in section 3. Because of the nature of packet loss in network of EPU, this, general, model must be adapted, as explained in section 4. It is proved that speech signal quality in EPU network depends on the number of nodes on the packet route. The graphics of rating factor (describing speech signal quality) for different number of nodes are presented.

The concluding remarks are emphasized in section 5: the speech signal quality in the EPU network depends on the number of nodes included in the packet route and it can be changeable during one connection.

2. PACKET NETWORK OF EPU

The structure of this packet network does not differ from the classic structure of computer networks [1]. It consists of user equipment, access routers and core routers. This equipment is located in the sites of EPU (power plants and substations) and is connected by the optical system of transmission which is associated with power line (OP GW). One usual packet telephone connection is presented in Fig. 1. The complete equipment for the presented connection is situated at power sites, $S1-Sn$. The packet telephone connection can pass different number of nodes, depending on the place of end users in the network and the alternate routing of speech packets.

![Fig. 1 – The model of packet telephone connection.](image-url)
One of the main characteristics of power sites, which does not exist in other networks, is the overvoltage interference, caused by the influence of power line switching on and off. Let \( k \) presents the number of disturbances in one power site during one call interval (or more generally, time interval) and let the duration of the \( j^{th} \) disturbance be \( t_{b_j}, j=1, 2, ..., k \). The time interval between the \( j^{th} \) and \( (j+1)^{th} \) disturbance can be expressed by \( t_{g_j}, j = 1, 2, ..., k-1 \). The mean duration time of overvoltage disturbance is \( T_b \) and the mean time interval between successive disturbances is \( T_g \). During the disturbance, the packets are corrupted and the erroneous speech packets are discarded either at network node or at receiving node. In the receiving node lost speech packets are presented by cumulative value of overall loss across the connection.

Fig. 2 – The disturbance caused by the power system (a, b, c), speech signal (g), digitalized speech signal (f), packetized speech signal (e), packet link under the influence of disturbance (d).
The influence of overvoltage disturbances on the packetized speech signal transmission in one network node is presented in Fig. 2. Figures 2a and 2b present overvoltage disturbances in power site. Fig. 2c presents overvoltage disturbances supposing the mean duration time of the disturbances and the mean duration time between the disturbances, \( T_b \) and \( T_g \). Figures 2g, 2f and 2e present speech signal, digitized speech signal and packetized speech signal, respectively. Fig. 2d presents packet link that is under the influence of overvoltage disturbance. In this figure the lost speech packets are also presented by the bold broken line. On Figs. 2f and 2g the part of the speech signal, which is lost in the packet transmission, is presented by the bold line.

The protocols TCP and SCTP are used for the reliable transmission of packetized data and telephone signaling. This data and signaling can be reconstructed using the well known procedures of retransmission. The packets of speech signal are sent using RTP/UDP protocol without retransmission in order to achieve low packet delay, and these packets can be lost if they are transmitted during the overvoltage disturbance. The part of lost packets is proportional to the part of time where overvoltage disturbances appear. The probability of packet loss in one site, considering the time interval before the first disturbance and after the last disturbance, can be expressed by:

\[
P_{pl} = \frac{k \cdot T_b}{k \cdot T_b + (k+1) \cdot T_g} = \frac{T_b}{T_b + \frac{k+1}{k} \cdot T_g}
\]  

or, as \( T_b \ll T_g \)

\[
P_{pl} \approx \frac{k}{k+1} \frac{T_b}{T_g}
\]  

The power switching events in one site are independent of each other and, for the sake of the simplicity of solution, the introduced power disturbances can be considered to make Poisson process at every site.

3. E-MODEL AND THE INFLUENCE OF LOST PACKETS

The calculation model which enables the estimation of speech signal quality influenced by different parameters, E-model, is described in [2]. The main equation of this model is:
where $R$ is the rating factor, which integrates all the influences on one connection and expresses them as numerical estimation of speech signal quality on the receiver side.

In the equation (2) the following parameters appear:
- the basic $R_0 \approx 94$,
- the influence of the simultaneous impairments ($I_s$),
- the influence of packet delay and echo ($I_d$),
- the influence of low bit-rate codecs and packet loss ($I_{e-eff}$),
- the psychological advantage factor ($A$).

In this paper we are only interested in the influence of packet loss. We suppose that $I_s = I_d = A = 0$, and the main equation of E-model becomes:

$$R = R_0 - I_{e-eff}.$$  \hspace{1cm} (2')

The influence of lost packets (and low bit-rate codecs) on speech signal quality at the receiving side is presented in [2], by the equation (3-29)

$$I_{e-eff} = I_e + \left(\frac{95 - I_e}{B_{pl}}\right) \cdot \left(\frac{P_{pl}}{\text{BurstR}} + B_{pl}\right),$$  \hspace{1cm} (3)

where the meaning of the variables is:
- $I_e$ – equipment impairment factor; it expresses impairment caused by the use of low bit-rate codec;
- $I_{e-eff}$ – effective equipment impairment factor. It is the value of $I_e$ corrected by the influence of packet loss;
- $P_{pl}$ – packet-loss probability in network expressed in percent, the values between 0,5% and 2% are often considered;
- BurstR – burst ratio, the factor which expresses Packet-loss burstiness;
- $B_{pl}$ – packet-loss robustness factor. The limiting value for $B_{pl}$ is 16. Above this value, i.e. if $B_{pl} \geq 16$, the speech signal quality is calculated using the formula (3). If $B_{pl} < 16$, some recommended values can be taken.

We suppose that speech signal is not compressed i.e. $I_e = 0$. The equation (3) becomes:
The value $B_{\text{burst}}$ is defined in [3]:

$$B_{\text{burst}} = \frac{\text{Average length of observed bursts in an arrival sequence}}{\text{Average length of bursts expected for the network under "random" loss}}$$

and can be calculated using Gilbert model [4], and the equation (3.30) from [2]:

$$B_{\text{burst}} = \frac{1}{p + q}, \quad (4)$$

where $p$ and $q$ are the transition probability between a "found" state (correct packets received) and a "loss" state (incorrect packets received, i.e. packets loss) in the Gilbert model with two states.

Let us note that $B_{\text{burst}}$ depends on the packet-loss burstiness only and not on the packet-loss probability.

In [3] the recommendations for the estimation of packet loss in some special cases of burst packet loss, for the packet-loss probability $\leq 2\%$ and the small value of packet-loss robustness factor ($B_{\text{pl}} < 16$), are presented.

4. PACKET LOSS AND ITS INFLUENCE IN EPU NETWORK

The Packet-loss Probability in the usual packet network can be calculated for the whole network. The influence of packet loss on the speech signal quality depends on the packet loss percentage, Packet-loss Burstiness and the (non)existence of packet loss concealment (PLC), as can be seen in [2] and [3]. In conventional networks, the number of causes for packet loss in one time interval is small, and the probability of packet loss is defined for the whole network. The packet loss in the network of EPU is caused by overvoltage disturbances and it is distributed across the whole network. It can be said that the packet loss probability in the EPU network depends more on the number of network nodes than in other networks.

Let us show that the usual method of packet loss influence on speech signal quality is not correct for the connections in the packet network of EPU, i.e.
the estimation of the speech signal quality (3') also depends on the number of nodes used for the connection.

We suppose that the mean disturbance duration time, $T_b$, and the mean time between successive disturbances, $T_g$, are the same at every site. In this case packet-loss probability is the same in every site. This assumption simplifies mathematical solution and does not influence significantly on the generality of the solution.

Packet-loss probability for the packet connection passing only one network node is:

$$P_{pl}(1) = \frac{T_b}{T_b + T_g}.$$  

Packet-loss Probability for the packet connection passing two network nodes is:

$$P_{pl}(2) = 1 - (1 - P_{pl}(1)) \cdot (1 - P_{pl}(1)) = 1 - (1 - P_{pl}(1))^2$$

or for $n$ nodes:

$$P_{pl}(n) = 1 - (1 - P_{pl}(1))^n.$$

The impairment factor for speech signal passing $n$ network nodes is now:

$$I_{e-eff} = \frac{95 \cdot P_{pl}(n)}{P_{pl}(n) + B_{pl}}.$$  (3'')

The influence of connection length, i.e. the number of sites included in one connection, on the connection quality, is presented in Figs. 3a, 3b, 3c, 4a and 4b. In these figures the decrease of speech signal quality is presented. It is calculated according to equation (3'') and expressed in the units of E-model ($R$ – rating factor), depending on:
- the percentage of lost packets at every site ($P_{pl} = 0.5\%$, $P_{pl} = 1\%$, $P_{pl} = 2\%$),
- the number of nodes included in the connection ($n = 1$, $n = 2$, $n = 3$) and
- the random nature of packet loss (for random loss $BurstR = 1$, for burst loss $BurstR > 1$).
The values in Figs. 3a–c are calculated for the limiting value of packet-loss robustness factor, $B_{pl} = 16$.

Fig. 3 – The value of rating factor ($R$) as the function of burst ratio (BurstR) for different values of packet-loss probability ($P_{pl}$).
From Figs. 3a, 3b, 3c, 4a and 4b the following conclusions are derived:
- the speech signal quality decreases with the increase of number of network sites on the connection route;
the decrease of speech signal quality is greater if the percentage of lost packets in the node is larger. For the random packet loss (BurstR = 1), and for $B_{pl} = 16$, the change of speech signal quality is, approximately:

$$\Delta R \approx -4 \cdot \Delta n \cdot P_{pl},$$

(5)

where the meaning of the values in equation is as follows:
- $\Delta R$ – the change of the speech signal quality,
- $\Delta n$ – the change of the number of nodes included in the connection,
- $P_{pl}$ – the probability of packet loss in one site expressed in %.

The relative decrease of quality is greater for burst packet loss than for random packet loss. This effect is more obvious for larger values of packet loss in one node.

5. CONCLUSIONS

The packet network of EPU consists of nodes located at power plants and substations of EPU. In every node the overvoltage disturbances, which can be the cause of packet loss, are generated. That's why the speech signal quality depends on the number of nodes included in the connection. Even more, it is important to notice that the speech signal quality in one connection can be changeable, depending on the number of nodes on the way of different speech packets. The change (decrease) of the speech signal quality is proportional to the number of nodes included in the connection. The decrease of the speech signal quality is also greater for the burst packet loss and for the small value of packet-loss robustness factor.

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