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A Survey on Modeling of Human States in Communication Behavior

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SUMMARY The Technical Committee on Communication Behavior Engineering addresses the research question "How do we construct a communication network system that includes users?". The growth in highly functional networks and terminals has brought about greater diversity in users' lifestyles and freed people from the restrictions of time and place. Under this situation, the similarities of human behavior cause traffic aggregation and generate new problems in terms of the stabilization of network service quality. This paper summarizes previous studies relevant to communication behavior from a multidisciplinary perspective and discusses the research approach adopted by the Technical Committee on Communication Behavior Engineering.

key words: *modeling, mental process, user satisfaction, QoE, user experience, user behavior, social network, human-network interaction*

1. Introduction

The growth in highly functional networks and terminals, such as a fourth-generation mobile network, smartphones and tablet PCs, have brought about a huge change in information communication environment. People use high-performance and high-functional Information Communication Technologies (ICT) devices and the proliferation of new ICT services has brought about greater diversity in lifestyles [1]. People more frequently enjoy web services, multimedia services and social networking services (SNS) and can enjoy much more variety of content and services than ever before. People can access such content and services anytime and anywhere they want.

High functional ICT devices and infrastructures increase the diversity of user behavior and free people from the restrictions of time and place. Freedom from restriction of usage environment promote the diversification of usage context. Considering a diversifying context of individual user plays a more important role in ICT system design. Additionally, a behavior of collective users shows a different facet of freedom from restriction of usage environment. Under unconstrained condition, the behavior that generates data traffic (we call it "communication behavior") is assumed to be dispersed widely and distributed evenly in time and space. However, patterns of communication behavior are in fact unevenly distributed. For example, traffic volume increases in transportation systems because people get together in the same place at the same time as they are following the same life rhythm. Traffic volume also increases at event sites and during the time popular TV programs are broadcast because people have similar preferences. Huge amounts of e-mail are sent at New Year because people are acting according to social convention. Such phenomena are caused by the similarities of user characteristics, including cognitive characteristics, preferences, lifestyles, social relationships and cultural background.

Traffic aggregation causes traffic congestion in Internet Protocol (IP) networks and degradation of service quality from a user experience (UX) perspective. To provide better service quality, controlling network quality is important in ICT service design. As described above, the distribution of data traffic dynamically changes and traffic either aggregates or diffuses depending on the user context. In addition to that, people select their behavior depending on the condition of the network. Some of them stop connecting to the Internet, others change to another service. Some people retry connecting repeatedly, which results in an additional increase in traffic and worsens traffic congestion. As a result, freedom from restriction of usage environment cause the dynamic change of traffic volume, service quality and user behavior and it is difficult to predict changes of them.

Even under a dynamically changing and unstable service environment, the demand for convenience, reliability and economy for communication networks remains very high. Stabilization of communication quality at low cost under such circumstances is an important and challenging task. Therefore, a method for the rapid and effective design and control of communication infrastructure taking communication behavior into account is required.

In order to cope with these problems, the authors established the Technical Committee on Communication Behavior Engineering (CBE) in 2011 [2]. The main research question of this committee is "How do we construct a communication network system that includes users?". The authors aim to develop new research approaches that deal with user behavior from multidisciplinary perspectives and develop new technology based on information and communication engineering. In this paper, we summarize relevant studies

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from the perspective of modeling and discuss the research approach for CBE.

2. Perspective of This Paper

2.1 Background

As described in Sect. 1, we address the challenge of developing methods for the design and control of a communication network system including users. The traditional approach for considering human factors in network engineering involves a subjective quality assessment of communication service users. The general methodology involves calculating the mean value of the level of satisfaction for voice or video stimulus on an n-point scale. This index is called MOS (mean opinion score). This subjective quality assessment quantifies the psychological response of users and is very useful for providing quality criteria for network planning [3].

However, users not only evaluate the quality of a network but also coordinate their behavior according to the network condition. They are not static evaluators. They are influenced by past experiences and change their behavior accordingly. Communication behavior is an interactive process between a person and a network. A new framework is required for evaluating this dynamic and interactive process of using a communication network.

2.2 Human-Network Interaction

Another approach for considering human factors in ICT usage is usability assessment for a user interface. The standard definition of usability is in ISO9241-11 [4]. In this standard, it is explained that usability consists of three elements, namely, effectiveness, efficiency and satisfaction. In a usability assessment, both psychological responses (i.e. satisfaction) and user behavior (i.e. effectiveness and efficiency) are analyzed taking the interactive process between the user and devices into account.

Employing this approach, Niida et al. [5] introduced the concept of "network usability". In order to define this concept, Niida et al. implemented a concept called "cognitive artifact". Norman defined a cognitive artifact as "an artificial device designed to maintain, display, or operate upon information in order to serve a representational function" [6].

When we look at a network from the perspective of cognitive artifact, it should be designed so that it has ability to maintain network statuses, display them, or operate the network. Figure 1 shows a conceptual diagram of the network regarded as a cognitive artifact [5]. This is one perspective for analyzing and describing the usage process that takes interactions between humans and the network into consideration (HNI: Human-Network Interaction).

2.3 Purpose of Modeling

To discuss communication behavior from the perspective of

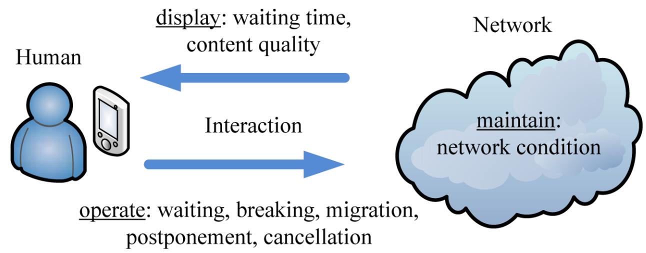

Fig. 1 Conceptual diagram of human-network interaction [5].

HNI, we can break down the process into three categories based on the concept shown in Fig. 1. The first one is the mental process of users in response to network status. Users react psychologically to the information displayed by the network, such as waiting time length and content quality. The second one is the behavioral process of users in response to the context of users. Users select a particular behavior depending on the circumstances and their psychological state. These two processes constitute the human process. The third one is the system process. It is the control of the network system based on user behavior.

The interactive approach to controlling a network requires all of the processes of these three categories. We have to combine research activities from different research areas. We need to establish common ground for collaboration. Modeling is one way to address this issue. Modeling is the activity of extracting the essence or optimum form of a mechanism, features and relationships from a complex system or reality, and to express this in figures, representations or mathematical formulae. The purpose of modeling is to make the observed phenomena reproducible or manipulatable. To take CBE as an example, modeling of human behavior helps us to develop the design and the technology for control. Modeling is important not only to gain a better understanding of human behavior but also to facilitate efficient collaboration in multidisciplinary research.

2.4 Composition of This Paper

The rest of paper is organized as follows. Section 3 discusses the requirement for modeling from an engineering application point of view. In Sect. 4, we discuss the modeling of a human mental process, namely, the reaction to feedback information from a network. In Sect. 5, modeling of a behavioral process, namely, the information input into a network, is discussed. Finally, Sect. 6 concludes the discussion.

3. Overview of Modeling from a Network Engineering Application Viewpoint

3.1 Background

In discussing integration of studies in order to understand humans and for design and control of communication systems, we first introduce studies in the network engineering field to show the requirements for modeling from an HNI viewpoint. There are two different applications: the design (planning in other words) purpose and the control purpose.

3.2 Design Purpose

One approach to network design is planning network capacity. This approach requires the criteria for network planning to be defined. For example, reference [7] defines the required QoS (Quality of Service) criteria for several services. It can also take subjective quality into account by combining QoS with QoE (Quality of Experience) mapping [8]. In these approaches, one value is required for a group of users as a criterion for the lower limit of capacity. From the perspective of modeling, a model for calculating the criterion value for a group of users is required. The other approach to network design is designing the architecture and the protocol. The requirements for modeling these approaches are discussed in the next paragraph because these approaches are closely related to network control. In both approaches, it is necessary to predict communication behavior because the network design precedes the launching of services.

3.3 Control Purpose

On the other hand, the measurement and feature extraction of communication behavior is needed in the control purpose because the network control occurs during operation. However, the mechanism for controlling a network must be prepared beforehand, meaning that communication behavior also needs to be predicted beforehand.

There are two different control objectives, one is related to the system and the other to users. The system is controlled by adapting to communication behavior. The legacy approach for controlling a system based on user behavior is a scheduling method. There are three conventional scheduling algorithms for a wireless network, namely, Maximum CIR (carrier-to-interference power ratio) [9], Round Robin [10] and Proportional Fairness [11]. These approaches control the order of packet selection in consideration of communication quality, sequence of access, cumulative traffic volume and so on.

The other approach to system control is rate control. This approach can be divided into three categories based on the target value. The first category utilizes static QoS target values [12], [13]. In this category, the transmission rate is controlled by maintaining a constant target QoS value. The second category utilizes static QoE target values [14]. The method employed in this category considers subjective quality by maintaining a constant target QoE value. The last category utilizes a dynamic QoE target value. This method controls the target QoE value by taking user context into account. In either case, the relationship between system parameters (i.e. the transmission rate) and system criteria is an important factor. From the perspective of modeling, a model for calculating the criterion value is required. For sophisticated control, the individual model is preferred but the collective model is also helpful.

The other approach is where users modify their behavior in order to adapt to network status when the user is regarded as the objective. Motoyoshi et al. [15] and Murase et al. [16] proposed a navigation system for behavior modification. They introduced a method called Comfort Route Navigation (CRN) which provides users with the optimal route for maximizing throughput in a heterogeneous network. The other approaches are utilizing pricing mechanisms to avoid network congestion [17] and visualizing the network for users so they can select the optimum network on their own [18]. From the perspective of modeling, a model that can describe the mechanisms involved in mental processes is required.

3.4 Categorization of Modeling

Considering the discussion in this section, authors introduce categorizations of modeling for the communication behavior as described below.

(1) Objective of Modeling:
individual user (individual model)
group of users (collective model)
(2) Description of Modeling
mathematical formula (mathematical model)
relationship between factors (factor model)
mechanism of process (process model)
relationship between users (network model)

In the era of telephone communication, the diversity of service usage was limited because only a voice communication service was provided over a fixed line. It is possible to model user behavior under a relatively simple premise and this may result in enhancing the versatility of the modeling. However, the popularization and sophistication of ICT increase the diversity of usage behavior, and this has led to the increasing complexity of modeling and also to the narrowing of the scope of applicability. It is necessary to develop a more complex model in order to describe and predict communication behavior accurately.

4. Modeling of Mental Processes

4.1 Background

In this section, studies related to modeling of mental processes are explained. We categorize the studies into four groups as described below.

(1) Subjective Quality Assessment
(2) Quality of Experience
(3) Time Perception Process
(4) Emotion and Motivation

The first one is research on subjective quality assessment. As described in Sect. 2, this is the most traditional approach to considering human factors in network engineering. Subjective quality assessment is related to utility studies. Utility is an economic term which refers to the sense of overall satisfaction users feel in relation to a service. In economics, it is explained that users' selection in the decision-making process under uncertainty is based on utility. (e.g. the expected utility theory [19], the prospect theory [20]). In these theories, a non-linear function is assumed between utility and good (e.g. money). We can apply this theory to communication services by replacing selection with behavior, utility with satisfaction, and good with a network parameter (e.g. the bandwidth, the waiting time duration). It can be assumed that users' behavior under the uncertainty communication condition is based on satisfaction rather than on a network parameter. There is a non-linear relationship between satisfaction and the network parameter.

Based on this theory, the MOS is calculated using a factor that has a dominant influence (dominant factor), such as the bandwidth or the waiting time duration, as a parameter. In addition, the context sensitivity of the MOS is widely discussed in the second category. The studies falling into the second category deal with many other factors (additional factor) that influence the MOS. The purpose of the studies in these two categories is the quantification of a psychological reaction. They rarely discuss the mechanism of the psychological reaction. In contrast, the studies coming under the third and fourth categories deal with the mechanisms of mental processes. Studies on the time perception process examine the influence of waiting time duration, which is the dominant factors in interactive services. The studies belonging to the fourth category examine the influence of additional factors.

From the perspective of modeling, the purpose of studies in the first category is formulating a mathematical model by quantifying psychological reactions. The mathematical model is designed to express a mental process by means of a mathematical formula. The studies in the second category also aim to formulate a mathematical model. In addition, the QoE studies consider additional factors, consequently, it can be said that these studies are actually dealing with a factor model. A factor model describes the relationship between factors. The other two categories are studies that attempt to elucidate the mechanisms of mental processes. These studies aim to create a process model. A process model describes related factors including the mechanisms that influence an observed object.

4.2 Subjective Quality Assessment

Based on the perspective of utility, the fundamental aim of subjective quality assessment is to formulate a utility function. This approach has a long history in the area of international standardization activities of the ITU (International Telecommunication Union). Here we categorize related studies into four traffic classes: conversational, interactive, streaming, and background as defined by Recommendation ITU-R M.1079 [21].

The typical use of the conversational class is telephony, including VoIP and videoconferencing. ITU-T Recommendation P.800 [22] and its related documents define the methods for subjective assessment of voice quality. Recommendations ITU-R BT.500 [23] and BS.1116 [24] define subjective assessment of the quality of television pictures and audio systems, respectively.

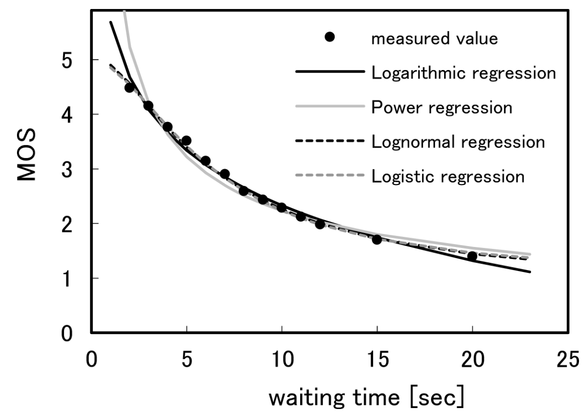

Fig. 2 The estimation result by regression models.

The interactive class consists of web browsing and downloading. In web access, empirical rules such as the eight-second rule [25] have been referred to in website design. ITU-T Recommendation G.1030 [26] defines the procedure for subjective quality assessment of website access on PCs. These Recommendations define the methodology for measuring the MOS. By utilizing the methodology described in these Recommendations, we can obtain the measured results.

For creating a mathematical model between the MOS and the network parameter, it is necessary to perform an analysis of measured results. Regression analysis, such as logarithmic regression analysis or power regression, is generally utilized. These regression analyses originate in the psychophysics field. H. Weber, a physiologist, and G. T. Fechner, a physicist, found the relationship between the actual change in a physical stimulus and the perceived change, which is known as the Weber–Fechner law [27]. That is "the intensity by which the standard must be increased to be noticed is proportional to the intensity of the standard" [28]. S. S. Stevens proposed the Stevens low [29], which is "perceived psychological magnitude is a power function of physical magnitude" [28]. These lows are determined from the results of experiments on the senses, such as the visual and tactile senses. However, they are closely correlated with the lows determined in subjective quality assessments. Figure 2 shows the results of the MOS in relation to the waiting time duration with four regression formulas. Table 1 shows the mean square error (MSE) of each regression model. As shown in the table, the differences among the regression formulas are small. Researchers can choose the regression formula suited to a particular purpose.

4.3 Quality of Experience

In ITU-T Appendix I to P.10/G.100 [30], QoE is defined as "The overall acceptability of an application or service, as perceived subjectively by the end-user.

Table 1 MSE applying four types of regression formula.

Regression model	α	β	MSE
Logarithmic regression	-1.46	5.69	0.0090
Power regression	-0.53	7.54	0.0617
Lognormal regression	-1.77	3.27	0.0024
Logistic regression	-1.06	1.96	0.0023

NOTES

a) Quality of Experience includes the complete end-to-end system effects (client, terminal, network, services infrastructure, etc.).

b) Overall acceptability may be influenced by user expectations and context."

Based on this definition, quality should be evaluated subjectively considering user context. Some studies have also been conducted on QoE for web access services on PCs [31], [32] and downloading services [33], [34], and the evaluation of tolerable waiting duration in cellular phone usage considering three factors: application classification, place of use, and degree of relaxation [35]. Some of the studies considered parameters other than the network QoS, such as price [36], [37] and usability [38]. In these studies, the relative influence of different factors is examined by introducing several additional parameters and finding the parameter that has an effect stronger than the others in a real use environment.

4.4 Time Perception Processes

In addition to the mathematical model and the factor model, studies have been conducted on process models in order to reveal the mechanisms of the mental processes. Such studies are conducted mainly in the field of psychology. One of the studies related to communication behavior examined the duration of time as perceived by human subjects (termed "psychological time"). Psychological time is the duration of time as perceived in contrast to the absolute time. In particular, the mental process that is involved in how individuals perceive the duration of time, called time perception, is closely related to the analysis of waiting behavior because it is well known that waiting in queues is a situation in which mental processes affect time perception. People feel that a long time has passed when they are in a hurry, and become irritated as a consequence. Several time perception models have clarified features of the cognitive process involved in the over- or under-estimation of absolute time [39]–[41]. There are other studies that focus on reducing the dissatisfaction associated with waiting. For example, Antonides, Verhoef, & van Aals [42] and Municho & Rafaeli [43] analyzed the effect of time fillers in telephone queues (fillers include music, apologies, and information about location in the queues) based on the results of field experiments and reported that such fillers are an effective way of reducing frustration when waiting.

4.5 Emotion and Motivation

A model of human emotion/motivation may be useful as well for understanding a user's attitudes or feelings in relation to information services. Although the investigation of human emotions has a long history, we still do not have a consensus of "what emotion is", including its definition [44], [45].

Models of emotional structure can be categorized into two types. One is the discrete emotional model, and the other is the continuous model. The discrete models of emotion, which have been influenced by Darwin's work in 1872 [46], assume that several types of basic emotion exist, and these are displayed and recognized universally [47], [48]. The number of basic emotions varies from study to study, but the following six emotions are common; anger, disgust, fear, happiness, sadness, and surprise. On the other hand, the continuous model of emotion, which has its origin in Wundt's work, assumes that there are two or more dimensions of emotion, and all emotion categories are mapped within its dimensional space [49]–[51]. Mapping of emotion in a two-dimensional space with the degree of valence and arousal space is commonly used (for a more detailed review of the models of emotion, see [45], [52]–[54]).

There are several methods currently used for monitoring or measuring human emotions. These methods can be divided into three categories; neuro-physiological, observer, and self-reporting methods.

Neuro-physiological methods of monitoring emotion target the detection of physiological alterations caused by emotional stimuli, such as electrocardiograph (ECG; heartbeat rate), blood pressure, electroencephalogram (EEG; brain-wave), galvanic skin response (GSR), functional MRI (brain activity). Neuro-physiological methods are able to capture relatively short-term changes, and is easier to find the relationship between cause and consequence. However, they have disadvantages such as participants' discomfort in having their mobility restricted and the discomfort caused by censoring equipment, and the difficulty of interpreting the results.

Observer methods monitor the observable behavior of participants, such as voice reaction, gesture, facial expression, and eye movements. Observer methods share the same problem that affects neuro-physiological methods, that is, it is difficult to interpret the results. However, in contrast to neuro-physiological methods, physical restrictions and discomfort to participants are negligible.

Self-report methods are considered to be the easiest and most efficient ways to measure the emotional states of participants, although it implicitly assumes that participants are able and willing to report their emotions [54]. Responses from subjects may be biased, as well. The MOS commonly used in QoE measurement would be categorized as a self-report method.

In the context of information communication behavior, especially in relation to "affective computing," the relationship between users' emotions and information services or information behavior has attracted attention. In the early years of the Internet, it was argued that a relationship existed between the user's emotions and web-searching strategies [55], and performance [56]. In relation to video games, it has been reported that reducing the player frustration results in longer playing time [57]. Scheirer et al. reported that an incremental increase in frustration leads to a change in both neuro-physiological measures (blood pressure, GSR) and observation measures (e.g., mouse clicking) [58]. A study investigating the relationship between neuro-physiological measures (GSR, heart beat rate) and the valence/arousal model using video game playing as an experimental environment has been reported as well [59].

Studies analyzing users' attitudes to content (e.g. video, music) have also been reported. For example, there have been studies that examined the relationship between EEG and self-reported emotional states for music content [60], [61] and video content (movie) [62]. Takahashi et al. examined the role of observable behaviors (body posture, head rotation), which were recorded using an RGB-D camera, to assess viewers' attitudes to TV programs [63].

5. Modeling of Behavioral Processes

5.1 Background

In this section, studies related to modeling of behavioral processes are categorized into two groups as described below.

(1) Modeling of traffic pattern
(2) Modeling of social network

The first one is a direct method for examining communication behavior. Traffic patterns can be simulated by applying this method. This form of modeling does not consider the relationship with other users; however, communication behavior cannot be separated from a relationship with others if the communication process is assumed to be interactive. The second one is modeling of social networks which considers relationships between users.

5.2 Modeling of Traffic Patterns

The modeling of data traffic generated in a communication network has been studied for a long time. In traffic theory, the network system is designed by modeling the reaction of the network in response to a stimulus to the network, for example, the pattern of generated traffic, at the interface between humans and the network. Earlier studies dealt with voice traffic in a circuit switching network. In this modeling, it is assumed that the arrival rate is distributed according to a Poisson process and the holding times are exponentially distributed. Correspondingly, blocking probability can be described by the Erlang B formula as indicated in the expression below.

$$B = \frac{\rho^c}{c!} \Big/ \sum_{n=0}^{c} \frac{\rho^n}{n!}, \tag{1}$$

where, B is the blocking probability, c is the number of identical parallel resources and ρ is the call number. This is the modeling of the system's reaction in response to communication behavior.

This modeling was simplified by making several assumptions related to communication behavior, such as memoryless property, for facilitating system analysis. However, it shows high consistency with an actual system in operation, and the parameters that can be calculated by the formula, such as the blocking probability and the average waiting time duration, can be utilized as system criteria. In addition, this can be used for both mathematical analysis and simulation analysis. This model is a flexible and useful example of modeling of communication behavior.

5.3 Modeling of Social Networks

The availability of large-scale and fine-grained data on communication behaviors drives research on social network analysis and modeling [64]–[66]. In social network analysis, social relationships among individuals in our society are analyzed by utilizing several types of data on communication behaviors such as records of mobile phones [67], [68], email [69], [70], and activities in SNS [71]–[73]. This research reveals the characteristics of social networks such as power-law degree distribution [69], small shortest path length [74], high clustering coefficient [74], and community structure [71], [75]. They also reveal the characteristics of communication patterns among individuals such as the heterogeneity in communication durations [68], and bursty communication behaviors [76], [77]. In contrast, research on social network modeling constructs models that can reproduce the characteristics observed in social network analyses. Several models have been proposed with some of the most popular being scale-free network models [78], [79], models of the strength of social ties [80], [81], and information diffusion models in SNS [82], [83].

Research on social network analysis and modeling are expected to help us to understand the relationships between social network structure and traffic patterns in communication networks. For instance, people in the same community in a social network have been shown to communicate with each other more frequently than with people in different communities [65], [84]. This suggests that the coarse-grained traffic demands of individuals can be inferred from their communities [65]. Moreover, a model predicting trends in SNS [85] can help to predict the occurrence of sudden bursty traffic in communication networks.

However, since most of the current social network studies focus on gaining a deep understanding of social phenomena, the existing models applied to social network research cannot be simply used for understanding, predicting, or controlling the traffic patterns in communication networks. While existing models can be used for understanding, and predicting the behaviors of individuals, the relationships between individual behaviors and traffic patterns in communication networks are still unclear. For efficient and effective design of communication networks that take the communication behaviors of users into account, we expect progress to be made in modeling the relationships between social network structure and traffic patterns in communication networks.

6. Conclusion

The new ICT technology frees users from the restrictions of time and place. However, it also generates new problems related to the design and control of communication networks. The dynamic changes in data generation make it more difficult to predict changes in service quality. Therefore, new strategies and technologies are required for future network systems. The authors established the Technical Committee of CBE in order to address the research question "How do we construct a communication network system that includes users?" from multidisciplinary perspectives. Our basic stance in relation to this research question is that communication behavior is an interactive process between a person and a network. From this viewpoint, users are regarded not as a static audience but as dynamic actors.

In this paper, modeling related to communication behavior was discussed. This kind of modeling is an effective way of integrating our understanding of communication behavior by means of a scientific approach and design and control of communication systems by means of an engineered approach. This type of modeling creates common ground among different research areas and thereby facilitates mutual understanding. We can change methodologies for designing and controlling networks by adopting this approach.

We showed how models can be categorized from an application perspective. The traditional network design method required system criteria. Many studies focused on providing collective and mathematical models. From an HNI perspective, it can be said that this research has been evolving by considering the user's perspective. However, this still not enough to solve the research question. We need to develop a new approach that can describe and predict the interactive processes of communication behavior. Modeling of communication behavior must shift from the collective to the individual, from describing states to describing processes. This approach would enable us to make the network infrastructure faster, more efficient and flexible.

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