

Towards Establishing Ambient Network Environment

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SUMMARY In this article, we introduce a new concept for the future information environment, called an “ambient information environment (AmIE).” We first explain it, especially emphasizing the difference from the existing ubiquitous information environment (UbIE), which is an interaction between users and environments. Then, we focus on an ambient networking environment (AmNE) which supports the AmIE as a networking infrastructure. Our approach of a biologically inspired framework is next described in order to demonstrate why such an approach is necessary in the AmIE. Finally, we show some example for building the AmNE.

key words: *ambient information environment, ambient networking environment, interactions, bio-inspired approach, dynamical system*

1. Introduction

The ubiquitous information environment (referred to as UbIE below) has been actively developed as the Internet becomes a societal infrastructure. However, it is now recognized that while the importance of the UbIE is apparent, its diffusion in the society is still limited. One reason is of course that it requires time for the new technology to be broadly utilized in the “ubiquitous fashion.” For example, in Japan, UNS R&D Strategic Program II is recently published to accelerate the research and development in the UbIE field towards the ubiquitous society [1]. In our view, however, more important is that we need “design principles” or “an overall architecture” for exploring the new technology like UbIE. Also, we consider that interactions among users and real/virtual environments should be explicitly involved in such a design principle of the new information environment. Taking into account those factors, we are now conducting the new project for AmIE [2], putting an emphasis on interactions between users and environments, which will be introduced later in this paper.

This article consists of four sections. In Sect. 2, we will introduce the AmIE, especially devoted to describing the difference from the existing UbIE. Section 3 describes the AmNE, and explains our originality. Also, some example is shown to introduce our approach. Finally we conclude this article in Sect. 4.

2. What is Ambient Information Environment?

2.1 Introduction to Ambient Information Environment

Broadly, “ubiquitous” is defined as:

interfaces, environments and technologies that allow users to be unaware of what it is they are using (invisible), and furthermore, to allow interactions anytime, anywhere, and by anyone.

However, it is a rather ambiguous statement, and often explained that in the UbIE, the user can access the network every time and everywhere by choosing the adequate communication medium. Technically, its realization would require environmental sensing to detect an existence of wired/wireless communication media and the choice of the adequate medium. However, it would be insufficient for building the actual information environment. For example, according to the network status, another media occasionally become more appropriate to the user. At that time, it should be chosen, but it is not usually considered in the UbIE.

What are missing? To discuss about it, let us review the related research activities. As an advanced information environment, an Ambient Intelligence (AmI) framework has recently been proposed [3], [4] as one of the European Commission’s central R&D programs. AmI takes the ubiquitous information environment one step further, and bases its ideas not on technology as its subject, but on human beings. It is centered on fundamental thinking on how to design spaces in which human beings carry out activities, such as homes, offices, streets, and the natural environment, so that they can be created with the following attractive qualities:

- Greater intellectual productivity (*Productivity*)
- Better health (*Healthcare*)
- More peace of mind in remembering (*Well-being*)
- Richer expressiveness (*Expressiveness*)
- Greater productivity (*Creativity*)

Based on these fundamental concepts, the AmI project is taking on following challenges:

1. Creating the most suitable space based on the person by making full use of information technologies
2. Giving functions to various objects that exist in a space, and seamlessly unify them from the sensor level to the

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global network layer in order to allow human beings to live and work in the space comfortably without them being aware of the devices and technologies

The Ambient Networks project [5] has also been conducted for supporting AmI. In the Ambient Networks project, the following scenario is introduced for a typical example requiring the AmIE [5]:

The Olympic Games will start in two days and Alice has got an assignment for the news-channel “Europe Today” to cover the Olympics. She flies in to Beijing and meets her crew. There is very little time to prepare, so Alice is glad that her Personal Area Network (PAN) connects to their PANs automatically without hassle. They now have one moving local network via which they can cooperate with. Since there are many local networks and service providers scattered all over the Olympic village, she needs to maintain connections with many of them even when she is on the move. Without Alice noticing it, her Ambient Network negotiates roaming with these operators and service providers. The crew prepare for a TV interview. The local network detects the need for an assured quality connection for the TV transmission and sets it up. A fallback channel is organized via another provider for quick handover in case the first connection fails.

As clearly mentioned in the above, the most important aspect of realizing the AmIE is that changes in access interfaces are realized without explicit or deliberate operation by users. Of course, it is insufficient that the communication device has a capability of choosing the most appropriate network interface available, as in the UbIE. Instead, the network-side is expected to provide the suitable network access method to the users. More broadly, the information environment should be adaptable to the changes of user’s requirement and environmental resources. It is an interaction between the user and environment, which we consider is the most important concept in realizing AmIE.

Another scenario showing that the interaction should be an essential part of the AmIE is as follows.

Consider that thermometers and hydrometers are distributed in the environment. They report that outside temperature is 35 degree Celsius and humidity is 80%. An air conditioner in a room keeps indoor temperature at 28 degree Celsius and humidity at 50% for comfort of people inside. Now, a boy is coming into the room. He is sweating, complaining about heat and humidity, and feels uncomfortable. Detecting his approach to the entrance and his condition, the air conditioner adjusts temperature around the entrance to 26 degree Celsius. When his discomfort is relieved, temperature around him is increased to 28 degree Celsius for his health.

See [6] for rich sources of the scenarios of the AmIE, where you could find more examples on how interactions are important in realizing the AmIE. The above-mentioned scenar-

ios are not only solved by the network; we need some information processing capabilities in the backend, where all the information required to get the current environment should be first collected. Then, the new environment is decided by the set of current environment and user’s requirement. For this purpose, we need some control method having a capability of time-changing environmental information; i.e., adaptive control method, which will be described in the next section. Note that while most of works in the UbIE have been missing the interaction in principle. It is a fundamental difference between UbIE and AmIE.

We last note that more recently, a new project called “Ambient Assisted Living (AAL)” is started in Europe [7]. The project is mainly intended to lower future social security costs. AAL aims that by the use of intelligent products and the provision of remote services including care services at extending the time older people can live in their home environment by increasing their autonomy and assisting them in carrying out activities of daily living; i.e., AAL is intended to improve the QOL (Quality of Life). Although the project itself does not directly refer to the ambient information environment, its realization would clearly require the AmIE, or AAL is one of important goals that the AmIE targets in the future.

2.2 Technical Aspects of AmIE

What are necessary to build the AmIE from a technological viewpoint? It is a next question. Below, we summarize the requirements for establishing the AmIE. First, the following four technological requirements are critical to realize the AmIE [3]:

1. Information technology is embedded in living spaces (*Embedded*).
2. The living space understands the conditions in which interactions between humans and the environment take place (*Context-aware*).
3. The living space brings about a suitable state based on the individual (*Personalized*).
4. The living space naturally transitions to the appropriate state for the environment and humans (*Anticipatory*).

In addition, in our project we especially place a heavy emphasis on the following requirement:

5. The environment and humans are harmonized; nothing is coerced (*Adaptable*).

In other words, in the AmI, human beings are the subjects, and the direction of the goals is to create a comfortable space that places the peripheral environment as subordinate to human beings. We, on the other hand, emphasize bringing about interactions between the environment and human beings and creating spaces that naturally transitions to more suitable conditions and harmonizes the interactions between the environment and human beings. We also place an emphasis on the creation of a flexible and adaptive information environment that fulfills requirements 1 to 5 above while

at the same time dynamically dealing with constant, unpredictable changes in conditions. This is a special feature compared to the AmI project.

Note that from the above perspective, the important information technology includes the networking as well as the interfaces. Also, the participation of social researchers in fields dealing intimately with human thoughts and actions, such as naturally language processing and interpersonal psychology, is essential. Actually, several researchers are participating from those fields, but in this paper, we focus on the networking aspect of the AmIE.

3. What is Ambient Networking Environment?

3.1 Our Approach

In our project, we consider the ambient networking environment (AmNE) supporting the AmIE, based on the following approaches.

1. Information environment controls network resources so that the user's anticipated environment is adaptively provided without user's knowledge on the current environment. Also, it should be realized without direct and explicit operation of users.
2. For realizing 1), it is preferable that the current status of the network is not provided through network management systems. Instead, the network should know the current status by itself actively, through, e.g., measurements. It is, we believe, only a possible solution for adaptive control according to the time-varying request made by users.
3. A fundamentally different point from the conventional network control methods is as follows: we include the changes of network environment and resources explicitly in the control model. Then, interaction between users/networks can be treated, so that the adaptability to environmental changes is realized.

Our originality lies in realization of adaptive control against changes of the user's requirement and/or the network environment as follows:

1. The control structure of the network resources is modeled by a dynamical system, in which changes of users' demands and network resources, i.e., environments are explicitly modeled.
2. The dynamical system is formulated based on a biological system, where interactions among entities are intrinsically included in the model.
3. Then, the target control system including network and users are driven as the dynamical system.

Essential is that the dynamical network control system described as a time-driven system can include the environmental changes, resource usage changes and users' demand changes in the model. Then, we can expect the adaptive system, robust against frequently occurring environmental changes of large-scale and complex information networks.

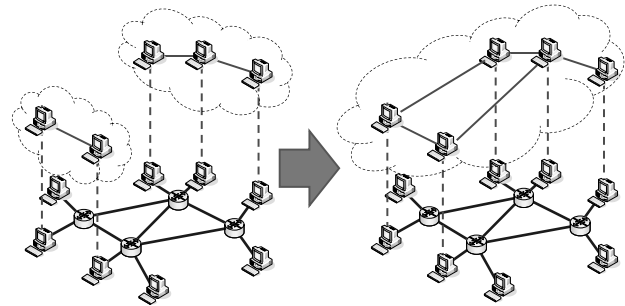


Fig. 1 Absorption composition model for merging networks.

Furthermore, it allows the network to be adaptive against the users' unexpected behaviors, which is in principle difficult to predict.

We last explain the difference from the Ambient Networks project [5], where the most important subject is how the user joins a new network according to the changes of the user's environment. Here, "changes" again mean, e.g., the user's mobility and/or the network failures. To treat "changes," the merging of the network is realized by utilizing overlay network techniques in [8]. They propose an absorption composition model and a gateway composition model. Figure 1 shows an example of the absorption composition model for two overlay networks; two links are added between overlay nodes to merge the network, and then the user can receive the service even from the other overlay network. In [8], they propose a solution by utilizing the algorithmic approaches. On the other hand, we are proposing a framework based on interactions between the user and the network, and among networks, which will be described in the next subsection. Also, our solution approach for network merge will be briefly explained in Sect. 3.4.

3.2 How Bio-Inspired Approach is Applied to AmNE?

In [9], [10], we successfully applied a biologically-inspired control method to the networking problem. It is called an attractor selection model. A basic form of the attractor selection concept is described in the following the Langevin equation, a class of the stochastic differential equation system:

$$\frac{d\mathbf{x}}{dt} = f(\mathbf{x}) \times \alpha + \eta \quad (1)$$

where $f(\mathbf{x})$ describes the system behavior against the state space \mathbf{x} , and α shows some goodness measure of the system behavior. In the context of information networks, it corresponds to performance metrics like the system throughput. An essential part of the above equation is the Gaussian noise term η which produces a randomness to escape from the local optimum.

It is based on the study of the cell biology [11]: why the biological system is so adaptive to the environmental changes, and robust eventually? In [11], the authors experimentally studied the effects of two mutually inhibitory

operons in E. Coli cells reacting to the lack of a nutrient in their exposed medium. A mathematical model was also proposed in [11], which is essentially stochastic N -differential equations.

$$\frac{dx_i}{dt} = f_i(x_1, \dots, x_N)\alpha + \eta_i, i = 1, \dots, N \quad (2)$$

The basic dynamic behavior can be described as follows. The system state contains all x_i and is derived from the concentrations of the messenger RNA (mRNA) molecules in the original model. The functions f_i define the attractors to which the dynamic orbit of the system will eventually converge in spite of the existence of an inherent noise term η_i . A key term is α , which is a non-negative function representing the cell's growth rate and is related to its activity. Essentially, this function influences the actual selection by switching between two modes of operation. In the first case, if $\alpha > 0$, the dynamics of Eq. (2) follows a rather deterministic way and the fluctuations introduced by will not influence the convergence to an attractor, under the condition that the noise amplitude is sufficiently small. On the other hand, when α approaches 0, the dynamics is entirely governed by η_i leading to a random walk in the phase space. Visit at [12] for more introductive explanation of the above modeling and solution approach, where Eq. (1) is called the YURAGI equation.

From the above, one could easily imagine that the attractor-selection model can be applied to the information network control methods, in which one solution is self-adaptively selected among a set of candidates utilizing the inherent noise in the system. That is, the selection follows the system dynamics embedded in a set of differential equations and the selection itself is performed without explicit rules, as each node simply follows the same dynamical pattern, as shown in it seems well suited for application in ambient network environments.

Actually, in [9], [10], the above modeling principle is applied to the multi-path routing problem in the overlay network as shown in Fig. 2. The overlay nodes are put on the top of the IP layer, and form the logical topology on which packet routing is realized. See There are multiple paths between source-destination pair. We want to select the best path for routing packets even if the traffic load changes, or the failure happens on the currently chosen path (Fig. 3). We formulate this problem as follows:

$$\frac{d\mathbf{m}}{dt} = \frac{s(\alpha)}{1 + \max(\mathbf{m})^2 - \mathbf{m}^2} - d(\alpha)\mathbf{m} + \eta \quad (3)$$

where $s(\alpha)$ and $d(\alpha)$ are the functions for synthesis and degradation. $m_i \in \mathbf{m}$ is the system state and corresponds to the transmission probability of packets using i -th path. Activity is measured at destination node according to some metric, of which typical example is the latency between source-destination nodes, and is returned to the source node. If the currently used path fails, or if the latency is increased due to the traffic changes, another path would be chosen according to the above equation system. Figure 4 shows

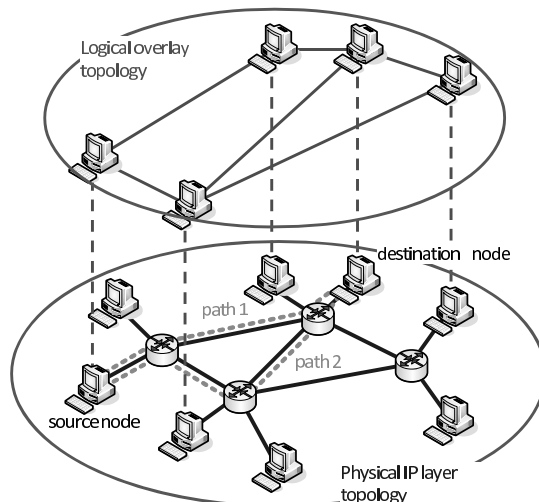


Fig. 2 Logical overlay topology over physical IP network.

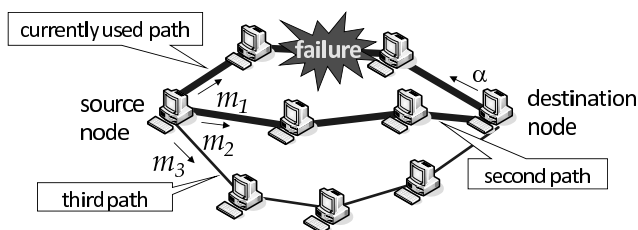


Fig. 3 Multiple paths between source-destination node pair.

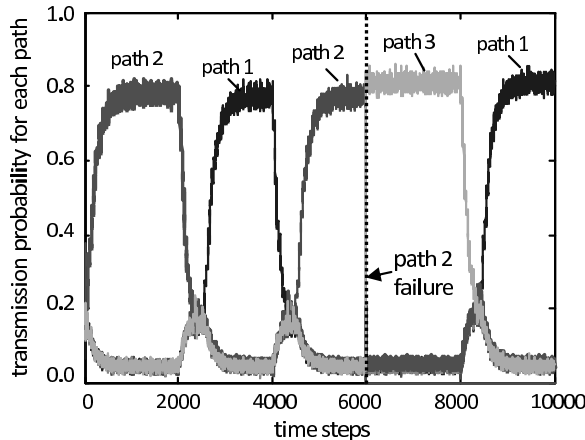


Fig. 4 Transmission probabilities are adaptively changed against traffic changes.

how the path is chosen among six paths. The horizontal axis shows simulation time and vertical axis does the normalized transmission probabilities. The figure shows the transmission probabilities on the paths are adaptively and adequately changed due to the randomly generated background traffic. It is also shown that even if the currently used path (path 2) fails, the next path (path 3) is immediately selected at around 6,000 time step.

Traditionally, a huge variety of optimization algorithms or quasi-optimization algorithms have been developed for

controlling networks. In most of those approaches, however, it is assumed that the current network status is known in advance. The network status may be obtained through real-time network measurements, but even in that case, the network is implicitly assumed to be static at least during the optimization problem is solved.

To explain the difference more clearly, consider the generic routing control problem. In the off-line control, if the failure happens within the network, pre-defined alternate route is established. It is controlled by the centralized node within the network. See Fig. 5(a). In the distributed routing like the IP routing, the update information on the neighbor node status is regularly exchanged. An optimal route for each source-destination pair is calculated by using some optimal problem solution method. Due to the difficulty of solving the global optimal problem, however, some heuristic solution approach is often used while the solution may be suboptimal (Fig. 5(b)). The intrinsic problem is that as the network becomes larger and more complex, even such a heuristic solution has a limitation in time and space. On the other hand, the dynamical system modeled by the time-evolving system always allows the up-to-date solution against the current network status (Fig. 5(c)). It may not be globally optimal, but instead it is adaptive even against the network failures.

One may consider the reinforcement learning takes a similar approach. In a sense, it is true. For example, ant-based routing (e.g., [13]), a class of swarm intelligence [14], can attain adaptive control, robust against environmental changes by introducing the noise. However, it is in general difficult to predict the system behavior due to its intrinsic nature of “emergency.” On the other hand, in the attractor-selection model, the whole system is driven by activity α .

As shown in the above, a highly dynamical control method becomes essential in the AmNE, where the time-varying network resources and/or users’ demands are pre-described in the model, so that the network becomes more adaptable and robust. In our project, we will extend the attractor selection model in two ways:

- Attractor perturbation model: in the attractor selection method, the noise term η is assumed to be fixed. Controlling it seems to be important for improving the convergence speed to a new optimum state against the environmental changes.
- Attractor composition model: it is a similar notion of merging of the multiple overlay networks in the Ambient Networks project, but we will establish it by extending the attractor selection model, such that the multiple networks, each of which is driven by the attractor selection model, are converged into a single network. We will illustrate an example realization of the attractor composition model in Sect. 3.4.

Presuming such dynamical control methods, a final goal of our project is to establish the new layered network architecture as a time-evolving system, which is often referred to as the a self-organizing system or emergent system, which will

be explained in the next subsection.

Of course, the control delay becomes a key factor when considering interactions. Fortunately, our attractor-selection model can be realized without computational burden, but still we will have to confirm if the control loop is acceptable to users. For this purpose, we plan to conduct the experiments, and the results might affect the structure of backends.

Finally, we comment on the importance of the interdisciplinary approach like ours. Establishing the new networking environment is of course an engineering problem. However, we have to have a scientific basis for designing the network. Traditionally, queuing and/or traffic theories have been used for this purpose. However, those can no longer become a basis for such purposes because in those approaches, the steady-state system behavior is of primary concern. For AmNE, we want to treat the time-dependent system, and to establish the robust and adaptive system. Fortunately, the biological system is essentially a dynamical system at least in the modeling phase. It is the reason why the biologically-inspired AmNE is so important. It is not just an analogy, but should be a basis of the interdisciplinary science/engineering approach, which is now widely recognized as a source of the innovation in the next technological era.

3.3 Our Architecture

From an architectural point of view, our system is essentially a self-organizing system. Formally, it is defined as follows [14]:

Self-organization is a set of dynamical mechanisms whereby structures appear at the global level of a system from interactions among its lower-level components. The rules specifying the interactions among the system’s constituent units are executed on the basis of purely logical information, without reference to the global pattern which is an emergent property of the system rather than a property imposed upon the system by an external ordering influence.

The biological system is also known as the self-organizing system, and in our case of the AmNE, the self-organizing system gives a new design methodology for understanding, designing and controlling the networks. It is because in the self-organizing system, entire behavior and/or functionality emerges only by interactions among neighbor entities, neither by the centralized node nor distributed information exchanges among all nodes, and these properties lead to many promising features in the networking system.

More technically, four mechanisms are required to realize self-organizing systems:

- Positive feedback permitting evolution and promotes creation of structure (reinforcement)
- Negative feedback regulating influences from previous bad adaptations (saturation, competition)
- Direct or indirect interaction among neighbor individ-

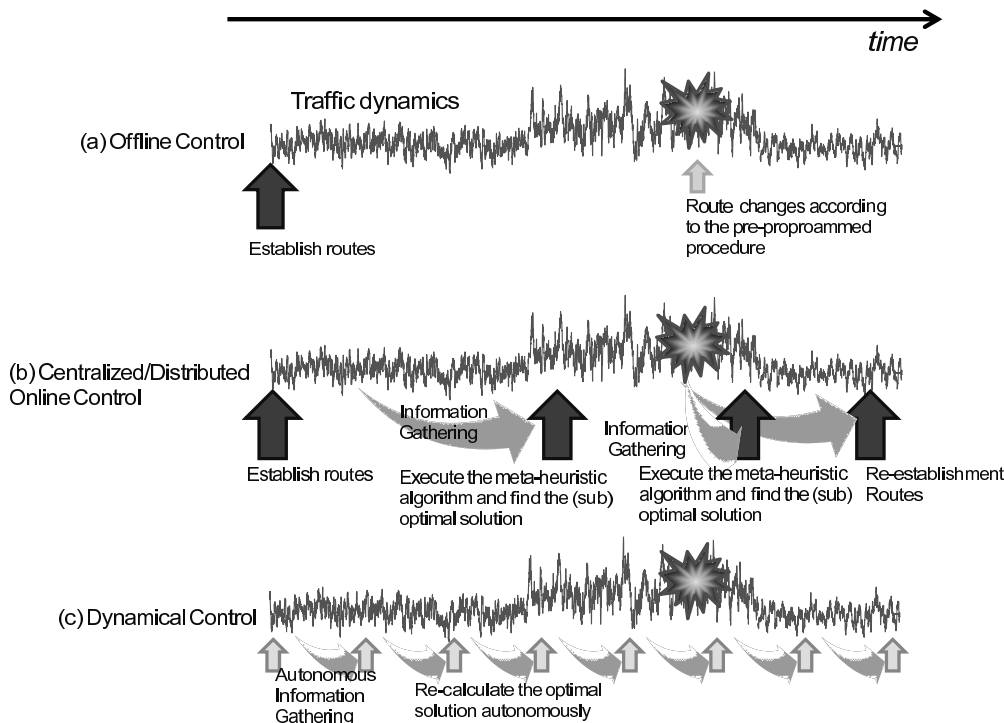


Fig. 5 A difference from the existing optimal solution algorithms.

uals

- Utilization of inherent randomness and fluctuations

The readers might notice that the stochastic time-evolving system discussed in the previous subsection is one representation of the above four principles. That is, our design principle based on Eqs. (1) or (2) are directly applied to the functional component of the self-organizing system.

The self-organizing system is quite different from the existing adaptive system (see, e.g., [15]). In the traditional adaptive system, the feedback time, i.e., control delay of the system is (often implicitly) assumed to be larger than the environmental changing time. In the self-management system, the feedback time can be smaller than the environmental changing time, and if the failure is detected, the backup component is immediately invoked. In the self-organizing system, on the other hand, the feedback time is smaller than the environmental changing time as in the self-management system, but the failure detection component is not included. Instead, the system behavior itself allows the dynamical changes of the system configuration.

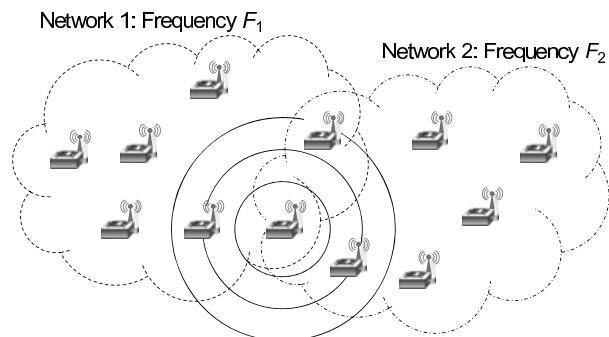
In summary, the biological system and the networking system based on it are the self-organizing system, having good features of a high degree of adaptivity and robustness. How to describe the interactions is not easy in general, and it is the reason that we learn much from the biological system.

3.4 Example of AmNE

Lastly, we show an example of the network control for supporting AmNE. Here, we consider the situation that

distributed devices dynamically form one or more networks or networked systems in accordance with the context, i.e., time, place, occasion, and individuals. To answer an inferred individual's desire, embedded networks would change their configuration by being connected with each other in part, merged into one as a whole, or divided into independent networks or devices, in an autonomous way. As described earlier, this problem has already been addressed in [8], but we treat the similar problem by utilizing the bio-inspired dynamical system [16], more specifically a pulse-coupled oscillator (PCO) model [17]. PCO is a mathematical model which explains synchronized behavior observed in biological systems, such as flashing fireflies and chirping crickets. Its notable feature is that all nodes (if applied to the wireless sensor nodes) can be synchronized without centralized control, and only stimulation among neighbor nodes is necessary for the entire synchronization of frequency, say F . See, e.g., [18] for a successful application of PCO to the synchronization mechanism in the wireless sensor network, in order to achieve power-saving in a self-organized manner.

In [18], all nodes are synchronized with the same frequency. In the AmNE, we want to establish an attractor composition of multiple networks having different attractors. See Fig. 6, where two networks having different frequencies (F_1 and F_2) encounter each other. Synchronization is accomplished through mutual interaction among nodes by stimulation. It implies that the degree of synchronization can be controlled by the degree of stimulation. That is, even though their operational frequencies are different, border nodes occasionally receive a message from two networks. Then, two networks can be synchronized through



The border node is a member of both networks, and stimulates the nodes of two networks.

Fig. 6 Attractor composition of two networks.

the border nodes. It is a network composition in the context of PCO. Of course there is a necessary condition for F_i 's to be satisfied. In our evaluation, synchronization appears among two networks with $F_1 = 1.0$ and $F_2 \leq 3.0$ [16]. The operational frequency of a merged network normally converges to the smaller frequency F_1 , but it can be drawn to intermediate frequency by gradual stimulation. In addition, the speed of synchronization can also be controlled by the degree of stimulation, that is, stronger stimulation leads to faster synchronization but at the sacrifice of the stability of synchronization. This is just a simple example of the attractor composition realizing the network merges, which is one necessary feature in AmNE. We are now researching more functions required in AmNE.

4. Concluding Remarks

In this article, we have first introduced the AmIE as a next step for the future information environment. We have explained what are different from the existing UbIE. One may consider that even UbIE considers the similar concept and solution approaches. The answer is YES and NO. Important is that we need to consider the interaction among entities (including users and environments). In the UbIE, it has already been pointed out, but there are few examples realizing it as the design principle. On the other hand, realization of AmIE requires involving the interaction explicitly. For that purpose, we are researching on bio-inspired AmNE. Without it, an ad-hoc solution would be utilized and it would result in shortening the span of the life of the technology.

Since our project is on-going, we have not shown the final goal clearly in the current manuscript. Visit at our website [2] for up-to-date research achievements.

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