IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received March 18, 2021, accepted April 7, 2021, date of publication April 15, 2021, date of current version April 26, 2021.

Digital Object Identifier 10.1109/ACCESS.2021.3073485

Home Network Traffic Control Scheme Based on Two-Level Bargaining Game Model

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ABSTRACT This article presents a new smart home network (SHN) traffic control scheme to adaptively handle different quality of service (QoS) traffic services. According to their special characteristics, we categorize the SHN traffic services into three classes - class I, II and III data services - to share the limited SHN bandwidth resource. To effectively share the limited resource, we adopt the bridging and iterated egalitarian bargaining solutions, and formulate a two-level cooperative bargaining game. At the over bargaining process, the idea of bridging bargaining solution is used to compromise the conflicting views of real-time and non real-time data services. At the under bargaining process, class I and class II data services share the assigned bandwidth based on the concept of iterated egalitarian bargaining solution. These both processes are implemented to take full advantages of collaborative SHN traffic services. This interactive coordinated paradigm explores the mutual benefits under dynamically changing SHN environments. The most important novelties of our two-level bargaining approach is to compromise diverse QoS requirements while leveraging a reciprocal consensus among different traffic services. In a coordinated manner, we can get a globally desirable solution to challenge the relatively fair-efficient gains. Finally, simulation testbed is constructed and the numerical analysis is conducted to demonstrate the performance improvement of our proposed method.

INDEX TERMS Smart home network, smart home gateway, cooperative bargaining game theory, bridging bargaining, iterated egalitarian bargaining.

I. INTRODUCTION

The advancement of new technologies has been driven to a great extent by the innovation and expansion, which play a central role in modern societies by enhancing social welfare and defining new ways for humans to interact with their environment. In the current century, a new paradigm allows humans to manage consciously the advanced information and communication technologies while improving their behaviors in the home area. A smart home refers to a convenient home setup where appliances and devices can be automatically controlled remotely from anywhere with the Internet connection by using mobile or other networked devices. Internet of thing (IoT) devices in the smart home are interconnected through the home area network, allowing the users to control functions such as security access to the home, temperature, lighting, and a home theater remotely. Naturally, the progress of smart home concept is due to the large scale introduction of novel technologies in all aspects of human existence based on the interaction between services and features [1], [2].

Smart home network (SHN) is a type of communication networks that facilitates communications among smart devices within the close vicinity of a home. Usually, smart TVs, sensors, electronic or electrical agents, home appliances, and intelligent IoT devices are connected, and they react with each other with user instructions or system controller. When connected with the Internet, the SHN can gain enhanced emergent capabilities such as home security, automation and entertainment. To ensure these requirements, SHNs are evolving rapidly while including heterogeneous service communications and a large number of IoT devices that generate different types of traffic data with different distributions. Under dynamic network environments, the fluctuation of SHN data distributions results in traffic congestions. Also, through the SHN, a variety of applications with different quality of service (QoS) requirements may raise the traffic control problem where multiple smart IoT devices simultaneously send their data. This situation requires

The associate editor coordinating the review of this manuscript and approving it for publication was Hayder Al-Hraishawi.

cooperative management of traffic loads while putting more constraints in smart home traffic scheduling issues such as congestion and delay. From the perspective of smart home service providers, ensuring different QoS requirements while maximizing the SHN performance is an important control task, and there are several approaches [2]–[5].

Smart home gateway (SHG) is a platform and an interface, through which IoT devices are compatible with one another. It can perform intelligent integration of multiple devices in one network, and has to process different types of smart home traffic data generated from several IoT devices in an optimal way to meet their QoS requirements. Usually, real-time traffic services, such as medical, fire detector, and online video streaming data, should be processed first, however, best effort traffic services may wait in the queue for a while before being processed by the SHG. Current QoS-aware scheduling methods in SHNs categorize these traffic services into three classes: class I (real-time random data), class II (real-time periodic data) and class III (best effort data) according to the required QoS. Class I, II and III traffic can be defined as critical, delay-sensitive and delay-tolerant services, respectively. To maximize the performance of SHN, the SHG should consider the best strategy to treat different traffic services in a fair-efficient fashion [3].

Traditionally, the SHG contains multiple queues and classifies the incoming data packets according to their priorities. In each queue, classified data packets are scheduled based on the SHG's strategy. Since the dynamic nature of today's SHN, multiple IoT devices can enlarge network system payloads. However, bandwidth in the SHN is an extremely valuable and scarce resource. Under the limited bandwidth constraint, the existing SHG scheduling methods do not seriously consider concurrent traffic services in their scheduling solutions. Due to this reason, the most challenging issue faced by the SHG operation is to make a decision for the bandwidth allocation based on the heterogeneity imposed by the different traffic services; it is a complex and difficult work in the dynamically changing SHN circumstances. Therefore, to design a novel SHG bandwidth allocation algorithm, we need a new intelligent control paradigm and novel solution concept [2]–[4].

A. BACKGROUND SECTION

The control scenario of SHG scheduling may fall into cooperative bargaining game theory. Therefore, we propose looking at the SHG's bandwidth allocation problem through the lens of bargaining theory. Originally, John Nash proposed a new idea of bargaining games in the 1950s; it is called as *Nash bargaining solution (NBS)*. The formal description of his idea consists of two components: a feasible set of utility allocations, each of which can be achieved via cooperation, and one special utility allocation, which is called the disagreement point, that prevails if the players do not cooperate. A bargaining solution is a function that picks a feasible utility allocation for every problem. Since then, various economists and scientists have extended the Nash's idea to various bargaining fields. Over the last seven decades, different bargaining solutions have been proposed based on slightly different assumptions about what properties are desired for the final agreement point [6], [7].

Another well-known bargaining solution is the *Kalai-Smorodinsky bargaining solution* (*KSBS*). Simply, we can think that the *NBS* can be used to maximize the system utility, and the *KSBS* ensures that all users incur the same utility penalty relative to the maximum achievable utility. Therefore, the *KSBS* can provide a different type of fairness as opposed to the *NBS* while keeping the optimality for all players [11].

In 2014, S. Rachmilevitch proposes a new bargaining solution concept, called the *bridging bargaining solution* (*BBS*), and characterizes the *BBS*, which generates formal axioms that capture the ideas of two standard bargaining solutions – the *NBS* and the *KSBS*. The *NBS* is the unique independent standard solution and the *KSBS* is the unique monotonic standard solution. Motivated by the goal to reconcile independence and monotonicity in the *NBS* and *KSBS*, the *BBS* has the requirement that it is at least as independent as the *KSBS*. That is, the monotonic standard solution is taken as the measuring stick for how far one game player can depart from independence. Therefore, in the *BBS*, each game player can receive at least the minimum of the payoffs he would have received under the *NBS* and *KSBS*. From the viewpoint of game players, the concept of *BBS* is how to bridge the gap between the ideas of *NBS* and *KSBS* [6].

In 2018, the *iterated egalitarian bargaining solution* (*IEBS*) has been developed based on the ideas of *egalitarian bargaining solution* (*EBS*) and *equal loss bargaining solution* (*ELBS*). Especially, the *EBS* and *ELBS* apply an egalitarian notion of justice in proposing outcomes to game players. More precisely, for each cooperative bargaining problem, the *EBS* proposes the maximum payoff profile that gives each player an equal gain over his disagreement outcome, whereas the *ELBS* proposes the maximum payoff profile that gives each player an equal loss over his best outcome. However, the *EBS* and *ELBS* fail to satisfy a basic desirable normative requirement that a solution should assign each player at least half of his best outcome in all bargaining problems. For two-player bargaining problems, the *IEBS* proposes a compromise in an iterative fashion, by using the proposed outcomes of *EBS* and *ELBS* at each iteration step [8].

Traditionally, a bargaining game solution is a set of the possible strategies and obtained when the game players act rationally and intelligently. Therefore, the solution concept of bargaining problems is the heart of cooperative game theory. Until now, the research literature has a rich history exploring various cooperative game's solution concepts, their axiomatic properties, and computability [6], [7].

B. MAIN CONTRIBUTIONS

According to the *BBS* and *IEBS*, we can effectively handle the traffic control problem in the SHN. In this study, we devise a dual bargaining game model to allocate the limited SHG's bandwidth allocation. First, we design the two-player over bargaining game. In this game, the player 1 represents critical and delay-sensitive traffic services, i.e., class I and class II data services, and the player 2 represents best effort services, i.e., class III data services. Under dynamic and diverse SHN environments, the player 1 and 2 make decisions to reach a mutually acceptable bandwidth sharing agreement through the *BBS*. Second, we design the two-player under bargaining game. In this game, the player I represents class I data services, and the player II represents class II data services. Based on the concept of *IEBS*, the player I and II adaptively share the assigned bandwidth amount, which is decided in the over bargaining game. By using the step-by-step interactive cooperative process, our two-level bargaining approach is flexible, adaptable and able to sense the dynamic changing smart home traffic environment in a coordinated manner. This feature leads to an appropriate QoS balance in the operation of SHNs. In detail, the major contributions of this study are summarized as;

- This study investigates the ideas of two different bargaining solutions to design our SHG bandwidth allocation scheme. By considering the smart home traffic characteristics, we formulate our scheme as a two-level bargaining game model to achieve a mutually desirable solution.
- At the over bargaining game model, the idea of *BBS* is used to compromise the conflicting views of real-time and non real-time data services. Through the *BBS*'s approach to bridge the gap between the ideas of *NBS* and *KSBS*, we can get a fair-efficient bandwidth allocation solution between different traffic services.
- At the under bargaining game model, class I and class II data services share the assigned bandwidth amount in the SHG based on the concept of *IEBS*. In an iterative fashion, we can compromise different viewpoints of *BBS* and *IEBS* to get a globally desirable solution.
- Based on the hierarchical combination of the over and under bargaining games, we explore the cooperative interactions while leveraging a reciprocal consensus among various traffic services.
- The advantages of our proposed scheme are illustrated by extensive simulation results. We can verify the correctness and synergistic features of our two-level bargaining approach by comparing with existing SHN traffic control protocols.

C. ORGANIZATION

The rest of the paper is organized as follows. Section II describes the related work about the smart home traffic scheduling problems. In Section III, we introduce the background knowledge of SHN infrastructure, and the fundamental concepts of *BBS* and *IEBS*. And then, some details are provided about our new two-level bargaining game model. To increase readability, the main steps of our proposed algorithm are given. Section IV contains a performance evaluation. It shows the accuracy and advantages of our proposed method by comparing the existing protocols. Finally, Section V draws some concluding remarks.

II. RELATED WORK

This section presents a brief review of various traffic scheduling strategies for SHNs. Most existing researches generally pay attention to the energy and power efficiency, and the SHG traffic control issue has not yet been actively considered. The paper [12] conducts a comprehensive and comparative review of the security features offered by the most commonly used or promising wireless personal area network technologies today, namely Bluetooth low energy, ZigBee, Z-Wave, Thread, and EnOcean. This study presents the state-of-the-art regarding the security aspects of each examined protocol, and offers a succinct, but all-encompassing, review of the works in the literature investigating certain security weaknesses per protocol. The current work can be used as a reference to anyone interested in obtaining a holistic view of the security requirements and potential pitfalls of such IoT protocols, and it is also expected to foster research efforts to the development of security-by-design solutions in the particular domain [12].

The GHOST - Safe-Guarding Home IoT Environments with Personalized Real-time Risk Control - project aims to develop a reference architecture for securing smart-homes IoT ecosystem [13]. It proposes a multi-layer solution that integrates traditional cyber-security countermeasures, while it introduces novel mechanisms for the efficient defence of common to IoT threats. The main idea is that the network activity of the smart-home environment is monitored and fed to the various detection modules which analyze and decide about potential cyber incidents. In turn, the GHOST's module responsible for the risk assessment evaluates the risk against the smart-home environment and either according to the user's preferences or autonomously it proceeds to the mitigation measures for the identified risk [13].

M. Attia et al propose the *Smart Home Heterogeneous Traffic Queuing* (*SHHTQ*) scheme based on the new queuing model. Traffic services, which are generated by heterogeneous smart home devices, need to meet their different deadlines while preserving the degree of criticality. Traditional traffic scheduling methods consider only the conventional priority metrics based on the IP type of service field to make a decision for bandwidth allocation. This conventional approach is not optimal to ensure the requested QoS, since the higher priority traffic may not require lower delay than lower priority traffic. To solve this problem, the *SHHTQ* scheme includes a dynamic queuing model for optimizing packet scheduling in the SHN with mixed arrival distributions. As a dynamic QoS-aware scheduling algorithm, this scheme considers both the critical nature of application traffic and its maximum allowed delay, and increases the maximum number of packets that can be processed by the SHG service. Finally, the effectiveness of the *SHHTQ* scheme is verified by the experimental results in terms of priority and delay satisfactions [2].

The paper [3] designs the *Smart Home Concurrent Traffic Scheduling* (*SHCTS*) scheme to process different types of traffic services. Under dynamic SHN environments, the fluctuation of network traffic distributions results in packets concurrency. Most existing smart home traffic scheduling methods do not examine the traffic synchronism problem in their scheduling solutions. By using probabilistic queuing disciplines, the *SHCTS* scheme presents an analytic model for a QoS-aware scheduling optimization of concurrent SHN traffic with mixed arrival distributions. For effective concurrent traffic operations, a hybrid QoS-aware scheduling problem is formulated and an innovative probabilistic queuing model is designed. In addition, the auction economic model of the game theory is adopted to provide a fair multiple access over smart home infrastructure, and the solution is implemented on both traffic sources and the home gateway. This game-theoretical model can be easily implemented in the SHG while serving a limited number of flows in the SHN [3].

L. Brewka et al develop the *Automatic Provisioning Smart Home Control* (*APSHC*) scheme while paying attention to the end-to-end QoS [9]. First, they concern the proposal of automatic classification of traffic flows for the resource reservation and assessment of required level of classification accuracy. This proposal allows the more automated QoS establishment between smart IoT devices and SHG. Aside from the establishment of QoS control mechanism within the SHN, they also focus on the interaction of SHG with the access network in order to extend the QoS provisioning as close as possible to service provider hosts. In addition, they present a simulation model and verify the performance improvement of the *APSHC* scheme; it can enable us to determine what accuracy of the classifiers is required to obtain satisfactory improvements. The simulation results clearly show that the *APSHC* scheme can properly classify traffic flows coming from different smart devices while raising the QoS level [9].

Although some existing methods have studied the SHG traffic control problem to improve the performance of SHNs, none of the research papers consider the two-level bargaining game approach from an interactive perspective. Due to the desirable features of cooperative game theory, we can get a fair-efficient SHG traffic control solution through our proposed approach. In our previous researches [14], [15], we also adopt different bargaining solutions to develop novel dual-level game models. The main merit possessed by our two-level game approach is to shed light on the practical control problem while providing excellent adaptability and flexibility to satisfy the different application requirements. In [14], [15], we can obtain practical solutions for sensor cloud control problem and 5G network control problem. In this study, we are able to confirm that our dual-level bargaining game paradigm is effectively applied to the SHG traffic control problem.

III. THE PROPOSED SCHEME FOR SHN TRAFFIC CONTROL ISSUES

In this section, we present the SHN platform, and introduce the basic ideas of *BBS* and *IEBS*. According to the classified traffic classes, we formulate our two-level bargaining game model to schedule the SHN traffic services. Finally, the main step procedures of our proposed SHN traffic control algorithm are delineated to help readers' comprehension.

A. SHN SYSTEM INFRASTRUCTURE AND BARGAINING GAME MODEL

Each SHN system includes many different smart IoT devices, and they offer various services to a wide range of application like monitoring, health assistance, safety, and energy efficiency. To ensure these services, multiple devices produce diversified traffic data with different QoS levels; they are mapped into different classes. Under the SHN traffic congestion situation, it is necessary to implement a rational and strategic control mechanism. The most challenging issue is to provide the end user's satisfaction in terms of QoS while maximizing the performance of SHN [2].

In the SHN, we assume that there is the set ($\mathbb{D}$) of multiple smart devices where $\mathbb{D} = \left\{\mathcal{D}_1, \mathcal{D}_{2,} \ldots, \mathcal{D}_n\right\}$, and these devices will generate data with different types and distributions. When these devices are activated, they have to send traffic simultaneously to the SHG. We have a single SHG in each SHN, and three different data queues, i.e., $\mathcal{Q}_I$, $\mathcal{Q}_{II}$ and $\mathcal{Q}_{III}$, are implemented in the SHG to handle the class I, II and III traffic data, respectively. The SHG contains two modules; classifier and allocator. The classifier classifies the incoming traffic depending on their data types, and traffic data are buffered into their corresponding queues. And then, the operator can process the traffic services based on the allocated bandwidth for each queue. We consider a discrete time model $T \in \{t_1, \ldots, t_c, t_{c+1}, \ldots\}$, where the length of a time slot matches the event time-scale at which control decisions are updated.

In this study, we formulate the SHG's bandwidth allocation process as a two-level bargaining model ($\mathbb{G}$). The over bargaining game $\left(\mathbb{G}^O\right)$ is modelled as a two-player game; class I and II traffic services are represented as one game player $\left(P_I^O\right)$ and the class III traffic service is defined as the other game player $\left(P_{II}^O\right)$. They gets their assigned bandwidth amounts, i.e., $\mathfrak{B}_I^O$ and $\mathfrak{B}_{II}^O$, through the concept of *BBS*. Since then, the $\mathfrak{B}_I^O$ amount should be distributed into class I and II traffic services. The under bargaining game $\left(\mathbb{G}^U\right)$ is also modelled as a two-player game; the class I traffic service is one game player $\left(P_I^U\right)$ and the class II traffic service is another game player $\left(P_{II}^U\right)$. They gets their assigned bandwidth amounts, i.e., $\mathfrak{B}_I^U$ and $\mathfrak{B}_{II}^U$, through the idea of *IEBS*. The $\mathbb{G}^O$ and $\mathbb{G}^U$ are repeated sequentially in a slotted time structure. Based on the interactive feedback manner, our SHG traffic control scheme is operated each time period during the step-by-step iteration.

In the proposed scheme, the amount of bandwidth allocation is specified in terms of basic bandwidth units to reduce computation complexity. Formally, we define $\mathbb{G}$ game entities for the SHN system infrastructure, i.e, $\mathbb{G} = \{\mathbb{G}^O, \mathbb{G}^U\} = \{\mathbb{D}, \{\mathcal{Q}_I, \mathcal{Q}_{II}, \mathcal{Q}_{III}\}, \mathfrak{B}, \{\mathbb{G}^O|(P_I^O, P_{II}^O), (\mathfrak{U}_I^O, \mathfrak{U}_{II}^O), (\mathfrak{B}_I^O, \mathfrak{B}_{II}^O)\}, \{\mathbb{G}^U|(P_I^U, P_{II}^U), (\mathfrak{U}_I^U, \mathfrak{U}_{II}^U), (\mathfrak{B}_I^U, \mathfrak{B}_{II}^U)\}, \mathfrak{B}_u, T\}$ of gameplay.

- $\mathbb{G}^O$ and $\mathbb{G}^U$ are over and under bargaining game models; they are related in an interactive manner of mutual and reciprocal interdependency.
- $\mathbb{D}$ is the set of the set of smart devices $\left(\mathcal{D}_{1\leq i\leq n}\right)$, which generate different types of traffic data.
- $\mathcal{Q}_I$, $\mathcal{Q}_{II}$ and $\mathcal{Q}_{III}$ are the queues in the SHG for class I, II and III data, respectively.
- $\mathfrak{B}$ is the total SHG bandwidth for SHN traffic services.
- In the $\mathbb{G}^O$, P_I^O and P_{II}^O are game players, and $\mathfrak{U}_I^O$ and $\mathfrak{U}_{II}^O$ are their utility functions, respectively. $\mathfrak{B}_I^O$ and $\mathfrak{B}_{II}^O$ are the allocated bandwidth for the P_I^O and P_{II}^O during the bargaining process.
- In the $\mathbb{G}^U$, P_I^U and P_{II}^U are game players, and $\mathfrak{U}_I^U$ and $\mathfrak{U}_{II}^U$ are their utility functions, respectively. $\mathfrak{B}_I^U$ and $\mathfrak{B}_{II}^U$ are the allocated bandwidth for the P_I^U and P_{II}^U during the bargaining process.
- $\mathcal{B}_u$ is a basic unit to allocate the bandwidth resource in the SHG.
- $T = \{t_1, \ldots, t_c, t_{c+1}, \ldots\}$ denotes time, which is represented by a sequence of time steps.

B. THE BASIC CONCEPTS OF BBS AND IEBS

Usually, a bargaining problem is a pair (S, d) where S is the feasible set and d is the disagreement point. $S \subset \mathbb{R}^n$ represents all possible utility agreements among the n bargain players where $\mathbb{R}^n$ be the n-fold Cartesian product of real number set $\mathbb{R}$. $d \in S$ is a point that specifies players' utilities in case they do not reach a unanimous agreement on some point of S. For all $x \in S$ and $y \in \mathbb{R}^n : d \leq y \leq x \Rightarrow y \in S$. Denote by $\mathbb{C}$ the collection of all such pairs (S, d). A solution is any function $\mathcal{F} : \mathbb{C} \to \mathbb{R}^n$ that satisfies $\mathcal{F}(S, d) \in S$ for all $(S, d) \in \mathbb{C}$. Given a feasible set S, the weak *Pareto* frontier of S is defined as $WP(S) \equiv \{x \in S : y > x \Rightarrow y \notin S\}$. The best that the player $1 \leq i \leq n$ can hope for in the problem (S, d) is $a_i(S, d) \equiv \max\{x_i : x \in S_d\}$ where $S_d \equiv \{x \in S : x \geq d\}$. Therefore, for all game players, the point $a(S, d) = (a_1(S, d) \ldots, a_n(S, d))$ is the ideal point of the problem (S, d). The *KSBS* is defined by $KSBS(S, d) \equiv WP(S) \cap [d; a(S, d)]$. On the other hand, the *NBS* is defined to be the unique maximizer of $\Pi_{1\leq i\leq n}(x_i - d_i)$ over S_d [10].

In bargaining theory, typical approach is to find a solution and captures a set of axioms that has a great deal of appeal. We can narrow down the set of meaningful and desirable axioms, to which the traditional bargaining solutions are required to adhere; i) *Pareto optimality* (*PO*): the selected solution should not be strictly dominated by another feasible solution, ii) *Symmetry* (*SYM*): the property remains un-changed under a set of operations or transformations, iii) *Invariance with respect to utility transformations* (*IRT*): the selected solution should be invariant under positive affine transformations of the bargaining problem. The *PO*, *SYM* and *IRT* are standard axioms for traditional bargaining solutions [6].

There are two additional axioms that will be considered in the sequel; iv) *Independence of irrelevant alternatives* (*IIA*) : the selected solution that clearly cannot be reached by voluntary behavior should not matter for bargaining, and v) *Monotonicity* (*M*) : if a bargaining problem expands in such a way, the increasing of bargaining set size in a direction favorable to a specific player always benefits that player. Within the class of traditional bargaining solutions, *IIA* and *M* axioms are incompatible. The *NBS* is a unique standard bargaining solution with the *IIA* axiom, and the *KSBS* is a different bargaining solution with the *M* axiom. The reconciliation of *NBS* and *KSBS* in bargaining is a serious challenging work [6], [7].

To bridge the gap between the *NBS* and *KSBS*, a new bargaining solution, i.e., *BBS*, has been introduced. For each $(S, d) \in \mathbb{C}$, this solution assumes that the player i temporarily gets his payoff as follows [6];

$$m_i(S, d) = \mathbf{min}\{NBS_i(S, d), KSBS_i(S, d)\} \tag{1}$$

According to (1), the *BBS* for the player i, i.e., $BBS_i(S, d)$, is given by [6];

$$\begin{aligned} &BBS_{1\leq i\leq n}(S, d) \\ &\equiv \begin{cases} m_i(S, d), & \text{if } NBS(S, d) = KSBS(S, d) \\ KSBS_{1\leq i\leq n}(\{x \in S : x \geq m(S, d)\}, m(S, d)), & \\ \qquad \text{otherwise} & \end{cases} \end{aligned} \tag{2}$$

It is easy to see that the *BBS* is a standard solution which is at least as independent as the *KSBS*. Simply, we assume a two-player bargaining game where $S \subset \mathbb{R}^2$. Given $x, y \in \mathbb{R}^2$, $x \preccurlyeq y$ is a partial order on the plane if $x_1 \leq y_1$ and $x_2 \geq y_2$. That is, $x \preccurlyeq y$ means that x is weakly to the north-west of y. If the following proposition (3) is true for every $(\mathcal{Q}, e) \in \mathbb{C}$, we can say that the *BBS* is at least as independent as the *KSBS* given (S, d) [6].

$$\begin{aligned} &\begin{cases} (KSBS(\mathcal{Q}, e) \preccurlyeq KSBS(S, d)) \\ \Rightarrow ((KSBS(\mathcal{Q}, e) \preccurlyeq BBS(\mathcal{Q}, e) \preccurlyeq KSBS(S, d))) \\ (KSBS(S, d) \preccurlyeq KSBS(\mathcal{Q}, e)) \\ \Rightarrow ((KSBS(S, d) \preccurlyeq BBS(\mathcal{Q}, e) \preccurlyeq KSBS(\mathcal{Q}, e))) \end{cases} \\ &\text{s.t.}, e = d, \mathcal{Q} \subset S \text{ and } x \in \mathcal{Q} \end{aligned} \tag{3}$$

Another new bargaining solution, the *IEBS*, has been introduced based on the *EBS* and *ELBS*. The *EBS* equalizes players' gains over their disagreement outcomes. If we simply assume a two-person bargaining problem, this corresponds to selecting the intersection point of the Pareto frontier and the 45-degree line drawn from the disagreement point. The *ELBS* equalizes players' losses from their ideal point outcomes. Therefore, the *ELBS* assigns to each $S \subset \mathbb{R}^2$, the point $ELBS(S) = a(S) - (\gtrdot, \gtrdot)$, where $\gtrdot$ is the minimum possible. This corresponds to selecting the point at the intersection

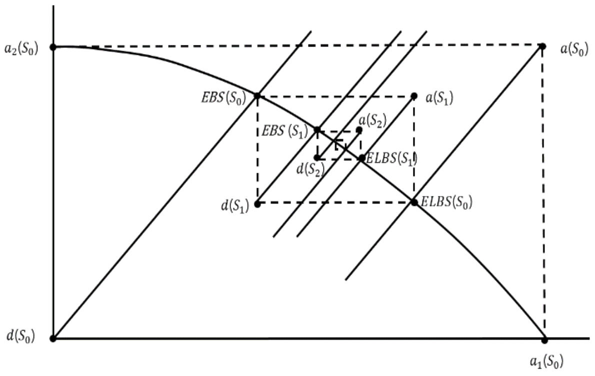


FIGURE 1. **Iterated egalitarian bargaining solution *(IEBS)*.**

of the Pareto frontier and the 45-degree line drawn from the ideal point. Note that if $a_1(S) > a_2(S)$, then $ELBS_1(S) > EBS_1$ and $EBS_2(S) > ELBS_2(S)$, and vice versa. Let $\mathbb{N}$ be the set of positive integer number. The *IEBS* assigns to each S, the point x, if $EBS(S) = ELBS(S) = x$ and assigns the point $y \equiv \cap_{\mathcal{T}\in\mathbb{N}} PO(S_{\mathcal{T}})$, where $S_0 \equiv S$ and the bargaining problem in iteration step $\mathcal{T}$, i.e., $S_{\mathcal{T}}$, for $\mathcal{T} \geq 1$ is derived by applying *EBS* and *ELBS* to $S_{\mathcal{T}-1}$ in a way that, the disagreement point and ideal point of $S_{\mathcal{T}}$ denoted by $d(S_t)$ and $a(S_t)$, respectively. [8].

$$d(S_t) = (\mathcal{I}, \mathcal{H}) \text{ and } a(S_t) = (\mathcal{K}, \mathcal{L})$$
$$\text{s.t.,} \begin{cases} \mathcal{I} = (\mathbf{min}\{EBS_1(S_{t-1}), ELBS_1(S_{t-1})\}) \\ \mathcal{H} = (\mathbf{min}\{EBS_2(S_{t-1}), ELBS_2(S_{t-1})\}) \\ \mathcal{K} = (\mathbf{max}\{EBS_1(S_{t-1}), ELBS_1(S_{t-1})\}) \\ \mathcal{L} = (\mathbf{max}\{EBS_2(S_{t-1}), ELBS_2(S_{t-1})\}) \end{cases} \tag{4}$$

Fig. 1 shows how the *IEBS* operates in a problem where the *EBS* and *ELBS* propose different outcomes. Basically, the *IEBS* could be interpreted as a conflict resolution mechanism, which resolves the conflict between *EBS* and *ELBS* in a step-by-step iterative manner, by using the minimal outcomes in each iteration as starting points and the maximal outcomes as ideals for the bargaining problem in the next step. Through same process repetitions, the *IEBS* converges to a single point [8].

The *IEBS* satisfies the axiom of *Midpoint domination* (*MD*), which requires the solution to provide the players' payoffs that are at least as large as the average of their best and worst payoffs where $ELBS(S) \geq (1/2 \cdot (a(S) + d(S)))$; the *MD* axiom is violated by the *EBS* and the *ELBS*. If we want to utilize an egalitarian justice issue in problems where the *EBS* and the *ELBS* disagree, the *IEBS* is a reasonable alternative in a domain that allows inter-players' utility comparisons [8].

C. THE TWO-LEVEL BARGAINING GAME MODEL FOR THE SHG

Each $\mathcal{D}_{1\leq i\leq n}$ generates independently different type traffic data. According to the data type, service priority is differently decided. In this study, the proposed SHN traffic control scheme is developed as a two-level bargaining game mode. At the over-level, the $\mathbb{G}^O$ is designed as a two-player game model, and it divides the total SHG bandwidth ($\mathfrak{B}$) into two parts; $\mathfrak{B}_I^O$ is assigned for the P_I^O and $\mathfrak{B}_{II}^O$ is assigned for the P_{II}^O where $\mathfrak{B} = \mathfrak{B}_I^O + \mathfrak{B}_{II}^O$. Under a dynamically changing SHN traffic environment, utility functions map the player-level satisfactions to real numbers, which represent the resulting payoffs. The utility functions of P_I^O and P_{II}^O at time t_c, i.e., $\mathfrak{U}_I^O(\cdot)$ and $\mathfrak{U}_{II}^O(\cdot)$, are formally defined as follows;

$$\begin{cases} \mathfrak{U}_I^O\left(\mathcal{S}I_{\mathcal{D}_i\in\mathbb{D}}^{t_c}, \mathfrak{B}_I^O\right) \\ = \phi \times \left(\dfrac{\lambda}{\kappa + exp\left(-\mu \times \dfrac{\mathbf{min}\left(\sum_{\mathcal{D}_i\in\mathbb{D}}\left(\mathcal{S}I_{\mathcal{D}_i}^{t_c}\right), \mathfrak{B}_I^O\right)}{\sum_{\mathcal{D}_i\in\mathbb{D}}\left(\mathcal{S}I_{\mathcal{D}_i}^{t_c}\right)}\right)} - \pi\right) \\ \mathfrak{U}_{II}^O\left(\mathcal{S}II_{\mathcal{D}_i\in\mathbb{D}}^{t_c}, \mathfrak{B}_{II}^O\right) \\ = \zeta \times \log\left(\dfrac{\mathbf{min}\left(\sum_{\mathcal{D}_i\in\mathbb{D}}\left(\mathcal{S}II_{\mathcal{D}_i}^{t_c}\right), \mathfrak{B}_{II}^O\right)}{\sum_{\mathcal{D}_i\in\mathbb{D}}\left(\mathcal{S}II_{\mathcal{D}_i}^{t_c}\right)} + \varepsilon\right) \end{cases} \tag{5}$$

where $\mathcal{S}I_{\mathcal{D}_i}^{t_c}$ is the generated class I and class II traffic data, and $\mathcal{S}II_{\mathcal{D}_i}^{t_c}$ is the generated class III traffic data from the $\mathcal{D}_i$ at time t_c. $\phi, \lambda, \kappa, \mu, \pi$ are coefficient factors for the $\mathfrak{U}_I^O(\cdot)$, and ζ, ε are coefficient factors for the $\mathfrak{U}_{II}^O(\cdot)$. $\mathfrak{U}_I^O(\cdot)$ and $\mathfrak{U}_{II}^O(\cdot)$, are monotone increasing functions. In this study, we adopt the idea of *BBS* to adjust the $\mathfrak{B}_I^O$ and $\mathfrak{B}_{II}^O$ values. Therefore, beforehand, we should know the *NBS* and *KSBS* for the $\mathbb{G}^O$ game. The $NBS_{P_I^O,P_{II}^O}$ is the *NBS* and the $KSBS_{P_I^O,P_{II}^O}$ is the *KSBS* for the P_I^O and P_{II}^O, respectively.

$$\begin{cases} NBS_{P_I^O,P_{II}^O} \\ = \underset{\mathfrak{B}_I^O,\mathfrak{B}_{II}^O}{\mathbf{max}} \left(\begin{matrix}\left(\mathfrak{U}_I^O\left(\mathcal{Q}I_{\mathcal{D}_i}^{t_c}, \mathfrak{B}_I^O\right) - d_{P_I^O}\right) \\ \times \left(\mathfrak{U}_{II}^O\left(\mathcal{Q}II_{\mathcal{D}_i}^{t_c}, \mathfrak{B}_{II}^O\right) - d_{P_{II}^O}\right)\end{matrix}\right) \\ KSBS_{P_I^O,P_{II}^O} \\ = \underset{\mathfrak{B}_I^O,\mathfrak{B}_{II}^O}{\mathbf{max}} \left(\begin{matrix}\dfrac{\left(\mathfrak{U}_I^O\left(\mathcal{Q}I_{\mathcal{D}_i}^{t_c}, \mathfrak{B}_I^O\right) - d_{P_I^O}\right)}{\left(\mathfrak{U}_I^O\left(\mathcal{Q}I_{\mathcal{D}_i}^{t_c}, \mathfrak{B}\right) - d_{P_I^O}\right)} \\ = \dfrac{\left(\mathfrak{U}_{II}^O\left(\mathcal{Q}II_{\mathcal{D}_i}^{t_c}, \mathfrak{B}_{II}^O\right) - d_{P_{II}^O}\right)}{\left(\mathfrak{U}_{II}^O\left(\mathcal{Q}II_{\mathcal{D}_i}^{t_c}, \mathfrak{B}\right) - d_{P_{II}^O}\right)}\end{matrix}\right) \end{cases} \tag{6}$$

where $d_{P_I^O}$ and $d_{P_{II}^O}$ are the disagree points of P_I^O and P_I^O, respectively. $\mathfrak{U}_I^O\left(\mathcal{Q}I_{\mathcal{D}_i\in\mathbb{D}}^{t_c}, \mathfrak{B}\right)$ and $\mathfrak{U}_{II}^O\left(\mathcal{Q}II_{\mathcal{D}_i\in\mathbb{D}}^{t_c}, \mathfrak{B}\right)$ are the ideal points of P_I^O and P_I^O according to (5). Based on the values of $NBS_{P_I^O,P_{II}^O}$ and the $KSBS_{P_I^O,P_{II}^O}$, the *BBS* for the P_I^O and P_{II}^O is given by;

$$BBS_{P_I^O,P_{II}^O} \equiv \begin{cases} \mathfrak{N}_{P_I^O,P_{II}^O}, & \text{if } NBS_{P_I^O,P_{II}^O} \\ = KSBS_{P_I^O,P_{II}^O} & \\ KSBS_{P_I^O,P_{II}^O} \text{ with } d_{P_I^O,P_{II}^O} & \\ = \mathfrak{N}_{P_I^O,P_{II}^O}, & \text{otherwise} \end{cases}$$
$$\text{s.t., } \mathfrak{N}_{P_I^O,P_{II}^O} = \mathbf{min}\left\{NBS_{P_I^O,P_{II}^O}, KSBS_{P_I^O,P_{II}^O}\right\} \tag{7}$$

where $d_{P_I^O, P_{II}^O}$ is a new disagreement point in the *BBS*. By using (7), the results of $\mathbb{G}^O$, i.e., the $\mathfrak{B}_I^O$ and $\mathfrak{B}_{II}^O$ amounts, are obtained.

At the under-level, the $\mathbb{G}^U$ is also developed as a two-player game model, and it divides the allocated $\mathfrak{B}_I^O$ into two parts; $\mathfrak{B}_I^U$ is assigned for the P_I^U and $\mathfrak{B}_{II}^U$ is assigned for the P_{II}^U where $\mathfrak{B}_I^O = \mathfrak{B}_I^U + \mathfrak{B}_{II}^U$. To effectively share the $\mathfrak{B}_I^O$ between P_I^U and P_{II}^U, the utility functions of P_I^U and P_{II}^U at time t_c, i.e., $\mathfrak{U}_I^U(\cdot)$ and $\mathfrak{U}_{II}^U(\cdot)$, are mathematically defined as follows;

$$\begin{cases} \mathfrak{U}_I^U\left(\mathcal{W}I_{\mathcal{D}_j \in \mathbb{D}}^{t_c}, \mathfrak{B}_I^U\right) \\ = \sigma \times exp\left(-\alpha \times \frac{\mathbf{min}\left(\sum_{\mathcal{D}_j \in \mathbb{D}}\left(\mathcal{W}I_{\mathcal{D}_j}^{t_c}\right), \mathfrak{B}_I^U\right)}{\sum_{\mathcal{D}_j \in \mathbb{D}}\left(\mathcal{W}I_{\mathcal{D}_j}^{t_c}\right)}\right) \\ \mathfrak{U}_{II}^U\left(\mathcal{W}II_{\mathcal{D}_j \in \mathbb{D}}^{t_c}, \mathfrak{B}_{II}^U\right) \\ = \beta - exp\left(-\eta \times \frac{\mathbf{min}\left(\sum_{\mathcal{D}_j \in \mathbb{D}}\left(\mathcal{W}II_{\mathcal{D}_j}^{t_c}\right), \mathfrak{B}_{II}^U\right)}{\sum_{\mathcal{D}_j \in \mathbb{D}}\left(\mathcal{W}II_{\mathcal{D}_j}^{t_c}\right)}\right) \end{cases} \tag{8}$$

where $\mathcal{W}I_{\mathcal{D}_j}^{t_c}$ and $\mathcal{W}II_{\mathcal{D}_j}^{t_c}$ are the class I and class II traffic data generated from the $\mathcal{D}_j$ at time t_c, respectively. σ, α are coefficient factors for class I data services, and β, η are coefficient factors for class II data services. $\mathfrak{U}_I^U(\cdot)$ and $\mathfrak{U}_{II}^U(\cdot)$, are monotone increasing functions. In this study, we use the concept of *IEBS* to adjust the $\mathfrak{B}_I^U$ and $\mathfrak{B}_{II}^U$ values. Therefore, in advance, we should know the *EBS* and *ELBS* for the $\mathbb{G}^U$ game. The $EBS_{P_I^U, P_{II}^U}$ is the *EBS* and the $ELBS_{P_I^U, P_{II}^U}$ is the *ELBS* for the P_I^U and P_{II}^U, respectively.

$$\begin{cases} EBS_{P_I^U, P_{II}^U} \\ = \underset{\mathfrak{B}_I^U, \mathfrak{B}_{II}^U}{\mathbf{max}}\left(\begin{matrix}\left(\mathfrak{U}_I^U\left(\mathcal{W}I_{\mathcal{D}_j \in \mathbb{D}}^{t_c}, \mathfrak{B}_I^U\right) - d_{P_I^U}\right) \\ = \left(\mathfrak{U}_{II}^U\left(\mathcal{W}II_{\mathcal{D}_j \in \mathbb{D}}^{t_c}, \mathfrak{B}_{II}^U\right) - d_{P_{II}^U}\right)\end{matrix}\right) \\ ELBS_{P_I^U, P_{II}^U} \\ = \underset{\mathfrak{B}_I^U \mathfrak{B}_{II}^U}{\mathbf{max}}\left(X_I = X_{II}\right) \end{cases}$$
$$\text{s.t.,} \begin{cases} X_I = \left|\mathfrak{U}_I^U\left(\mathcal{W}I_{\mathcal{D}_j}^{t_c}, \mathfrak{B}\right) - \mathfrak{U}_I^U\left(\mathcal{W}I_{\mathcal{D}_j \in \mathbb{D}}^{t_c}, \mathfrak{B}_I^U\right)\right| \\ X_{II} = \left|\mathfrak{U}_{II}^u\left(\mathcal{W}II_{\mathcal{D}_j}^{t_c}, \mathfrak{B}\right) - \mathfrak{U}_{II}^U\left(\mathcal{W}II_{\mathcal{D}_j \in \mathbb{D}}^{t_c}, \mathfrak{B}_{II}^U\right)\right| \end{cases} \tag{9}$$

According to (9), the $EBS_{P_I^U, P_{II}^U}$ and the $ELBS_{P_I^U, P_{II}^U}$ are obtained, and we set them as the first round temporal solutions. And then, for the next round, we can get a new ideal point, i.e., a_{i+1}, and a new disagree point, i.e., d_{i+1}, as follows;

$$\begin{cases} a_{i+1} = \left(a_{i+1}^I, a_{i+1}^{II}\right) \\ = \left(\mathbf{max}\left(EBS_{P_I^U}, EBS_{P_I^U}\right), \mathbf{max}\left(EBS_{P_{II}^U}, EBS_{P_{II}^U}\right)\right) \\ d_{i+1} = \left(d_{i+1}^I, d_{i+1}^{II}\right) \\ = \left(\mathbf{min}\left(EBS_{P_I^U}, EBS_{P_I^U}\right), \mathbf{min}\left(EBS_{P_{II}^U}, EBS_{P_{II}^U}\right)\right) \end{cases} \tag{10}$$

Based on the values of a_{i+1} and d_{i+1}, the second round's temporal solutions are obtained through the negotiation of *EBS* and *ELBS*. By iteratively repeating this process, we can approach the $IEBS_{P_I^U, P_{II}^U}$ while adjusting the difference between the *EBS* and *ELBS*.

D. MAIN STEPS OF PROPOSED SHN TRAFFIC CONTROL SCHEME

Smart applications are becoming more common within the home, and the SHG has to process different types of network traffic generated from several devices in a strategic way to meet their QoS requirements. However, they must compete for the limited SHG's bandwidth. Such competition should be handled intelligently to maximize the SHN system performance. Current existing traffic scheduling methods in SHNs do not consider an interactive perspective among different data types. In this article, we present a new bandwidth allocation algorithm in the SHG to effectively handle the SHN traffic services. To design our proposed scheme, the main challenge is to achieve globally desirable goals such as network efficiency and QoS provisioning. To satisfy this goal, we adopt the ideas of bargaining game theory and develop a novel two-level game model. At the over-level game, we decide the bandwidth amounts for class I, II and class III traffic services while implementing the concept of *BBS*. Based on the result of our over-level game, the lower level game redistributes the assigned bandwidth amount into class I and class II traffic services by using the concept of *IEBS*. According to our two-level bargaining game approach, we can get some advantages to provide a fair-efficient solution while ensuring the required QoS. The main steps of our proposed scheme can be described as follows, and they are described by the following flowchart:

Step 1: For our simulation analysis, the values of coefficient parameters and control factors can be found in Table 1, and the simulation scenario is given in Section IV.

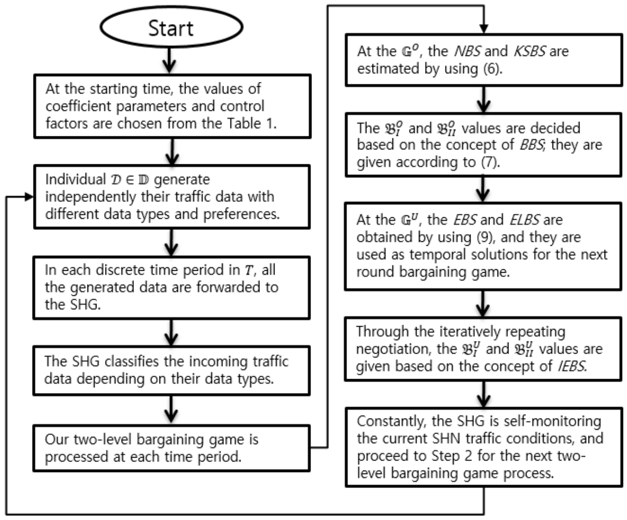
Step 2: In each discrete time period in T, individual $\mathcal{D} \in \mathbb{D}$ generate independently their traffic data with different data types and preferences. All the generated data are forwarded to the SHG.

Step 3: At each time period, the SHG classifies the incoming traffic data depending on their data types, and allocates the limited bandwidth resource ($\mathfrak{B}$) for different traffic services based on the two-level bargaining game model.

Step 4: At the over-level game, the game player P_I^O and P_{II}^O's utility functions, i.e., $\mathfrak{U}_I^O(\cdot)$ and $\mathfrak{U}_I^O(\cdot)$ are defined by using (5), and the $\mathfrak{B}_I^O$ and $\mathfrak{B}_{II}^O$ values are decided based on the concept of *BBS*.

Step 5: To obtain the $\mathfrak{B}_I^O$ and $\mathfrak{B}_{II}^O$ values, the *NBS* and *KSBS* are estimated by using (6), and the final *BBS* solution is given according to (7).

Step 6: At the under-level game, the game player P_I^U and P_{II}^U's utility functions, i.e., $\mathfrak{U}_I^U(\cdot)$ and $\mathfrak{U}_I^U(\cdot)$ are



Flowchart. 1. **Flowchart of the proposed algorithm.**

defined by using (8), and the $\mathfrak{B}_I^U$ and $\mathfrak{B}_{II}^U$ values are given based on the concept of *IEBS*.

Step 7: To get the $\mathfrak{B}_I^U$ and $\mathfrak{B}_{II}^U$ values, the *EBS* and *ELBS* are obtained by using (9), and they are used as temporal solutions for the next round bargaining game. Through the iteratively repeating negotiation, we can adjust the difference between the *EBS* and *ELBS* according to (10).

Step 8: This process continues until the difference of *EBS* and *ELBS* is smaller than $\mathfrak{B}_u$. Finally, the $\mathfrak{B}_I^U$ and $\mathfrak{B}_{II}^U$ values is obtained.

Step 9: Constantly, the SHG is self-monitoring the current SHN traffic conditions, and proceed to Step 2 for the next bargaining game process.

IV. PERFORMANCE EVALUATION

In this section, we build a simulation model to evaluate the performance of the proposed scheme, and discuss the results of the simulation experiments by comparing the *SHHTQ*, *SHCTS*, *APSHC* protocols in [2], [3],[9]. To develop our simulation model, we have used the simulation language 'MATLAB'. MATLAB's high-level syntax and dynamic types are ideal for model prototyping, and it is widely used in academic and research institutions as well as industrial enterprises. To validate our approach, we consider three metrics: i) the success percentage of class I data services, ii) the success percentage of class II data services, and iii) SHN system throughput. First, we describe the experimental settings and simulation scenario, and then, present the numerical analysis. The assumptions of our simulation environments are as follows:

- The simulated SHN system platform consists of 10 smart devices where $|\mathfrak{D}| = 10$.
- Multiple smart devices are locally dispersed over the SHN area; they are connected to the single SHG.
- The SHG has three data queues, i.e., $\mathfrak{Q}_I$, $\mathfrak{Q}_{II}$ and $\mathfrak{Q}_{III}$, and these buffer sizes are the same as 5 Gbits.

TABLE 1. **System parameters used in the simulation experiments.**

Parameter	Value	Description
n	10	the total number of smart devices
$\mathcal{B}$	50 Gbps	the total SHG bandwidth for SHN traffic services
$\mathcal{B}_u$	512 Mbps	basic bandwidth unit for bandwidth allocation
$\|\mathcal{Q}\|$	5 Gbits	buffer sizes for each SHG queue
σ , α	1.5 , 1.2	coefficient factors for class I data services
β , η	1 , 3	coefficient factors for class II data services
ϕ, λ, κ	2, 1, 1	coefficient factors for $\mathfrak{U}_I^O(\cdot)$
μ, π	-5, 0.5	coefficient factors for $\mathfrak{U}_I^O(\cdot)$
ζ , ε	3.5, 1	coefficient factors for $\mathfrak{U}_{II}^O(\cdot)$

Traffic Type	Application	Bandwidth Requirement	Service duration
Class I	1	10 Mbps (hard delay limit)	10 t
	2	45 Mbps (hard delay limit)	20 t
	3	15 Mbps (hard delay limit)	40 t
Class II	4	30 Mbps (hard delay limit)	30 t
	5	40 Mbps (hard delay limit)	45 t
	6	35 Mbps (hard delay limit)	15 t
Class III	7	20 Mbps (soft delay limit)	60 t
	8	25 Mbps (soft delay limit)	90 t
	9	50 Mbps (soft delay limit)	35 t

- The total SHG bandwidth amount ($\mathfrak{B}$) for SHN traffic services is 50 Gbps.
- Each smart device $\mathfrak{D}_{1 \le n \le n}$ generates its data for SHN traffic services. The generation process for data services is Poisson with rate Λ (services/t), and the range of offered services is varied from 0 to 3.0.
- The disagree points in $\mathbb{G}^O$ and $\mathbb{G}^U$ are set to zeros, respectively.
- Nine different kinds of data services are assumed based on their bandwidth requirements, priorities for the delay sensitivity, and service duration times; they are assumed as the SHN's traffic load.
- To reduce computation complexity, the amount of bandwidth allocation is specified in terms of basic bandwidth unit ($\mathfrak{B}_u$), where one $\mathfrak{B}_u$ is the minimum amount (e.g., 512 Mbps in our system) of allocation process.
- System performance measures obtained on the basis of 100 simulation runs are plotted as a function of the offered service request load.
- We assume the absence of physical obstacles in the experiments.

The evaluation results of success percentages of class I and II data services are shown in Fig. 2 and Fig. 3. Based on the concept of *BBS*, the $\mathbb{G}^O$ adaptively makes control decisions to allocate the SHG bandwidth resource for them. As a function of the service generation rate increase, class I and II data services are preferred over class III data services in the bandwidth allocation process. And then, the assigned bandwidth $\left(\mathfrak{B}_I^O\right)$ for class I and II data services is shared

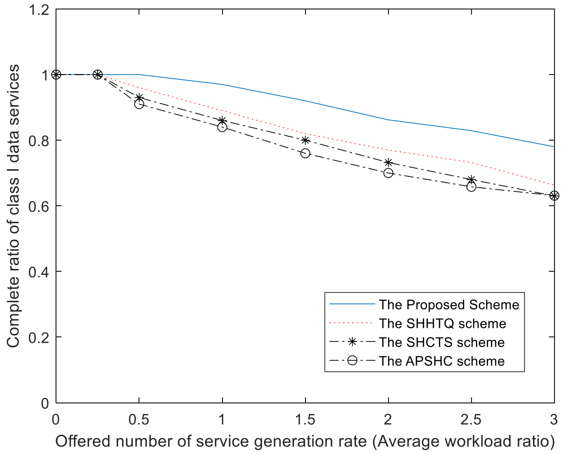


FIGURE 2. The success percentage of class I data services.

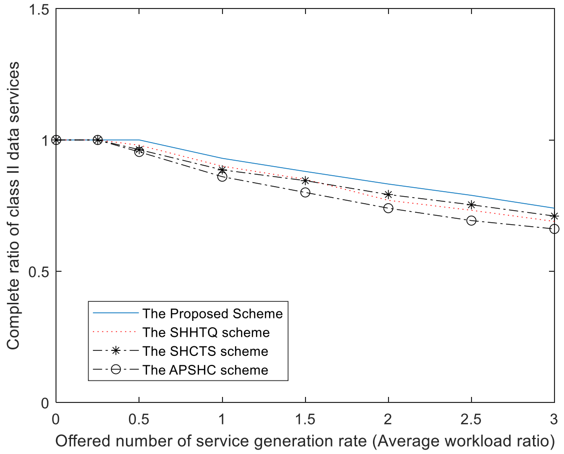


FIGURE 3. The success percentage of class II data services.

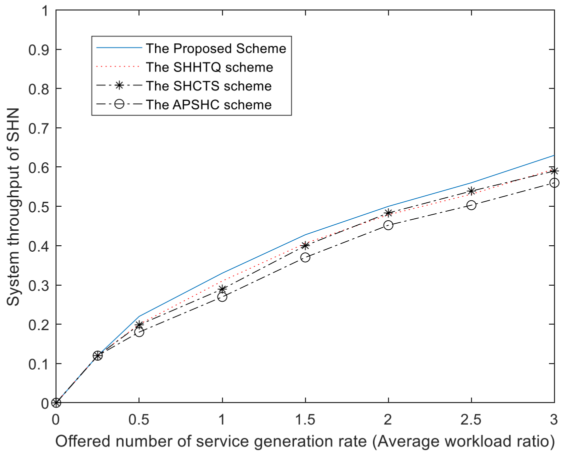


FIGURE 4. SHN system throughput.

effectively. According to the idea of *IEBS*, we leverage the P_I^U and P_{II}^U to work together for their profits. When the average workload ratio is low (below 0.25), the performance of the four schemes is identical. This is because all schemes have enough bandwidth resources to accept all requested traffic services. However, under heavy SHN traffic load intensities, the curves indicate that our proposed scheme improve the performance of class I and II traffic services more significantly than the existing *SHHTQ*, *SHCTS*, *APSHC* schemes.

In Fig. 4, we depict the SHN system throughput when the service generation rate increases. As expected, we observe that the traffic load is low ($\Lambda \ \leq 0.25$), the performance of the all schemes is identical. It is the same reason as it is for Fig. 2 and Fig. 3. As the service generation rate increases, we can attain the better SHN system throughput than other existing state-of-the-art protocols. From the simulation results in Fig. 2-Fig. 4, it is evident that we can effectively compromise conflicting requirements to provide the most proper SHN control solution.

V. SUMMARY AND CONCLUSION

With the advent of multiple smart appliances into the modern houses, the SHN system is becoming increasingly important. In a dynamic SHN environment, the effective bandwidth sharing approach is an effective way to maximize the performance of home networking. In this paper, we present an efficient SHN traffic control scheme based on the cooperative game theory. To handle the bandwidth allocation problem in the SHG, we adopt the ideas of *BBS* and *IEBS* to formulate the two-level bargaining game model. At the over-level, the *BBS* can solve the gap between *NBS* and *KSBS* to allocate the SHG's bandwidth amount for class I, II and class III traffic data. At the under-level, the *IEBS* can reconcile the difference between *EBS* and *ELBS* to share the assigned bandwidth for class I and class II traffic data. During the interactive operation, our two-level bargaining approach attempts to ensure different QoS services in order to optimize the usage of the SHG bandwidth resource. Under widely diversified SHN traffic situations, we can provide globally desirable system-wide properties while achieving greater and reciprocal advantages for different QoS requirements. Finally, we test our method by using extensive simulation experiments, and show that our proposed approach increases the SHN performance in the system as compared with the existing *SHHTQ*, *SHCTS*, *APSHC* schemes.

ACKNOWLEDGMENT

This research was supported by the MSIT (Ministry of Science and ICT), Korea, under the ITRC (Information Technology Research Center) support program (IITP-2021-2018-0-01799) supervised by the IITP (Institute for Information & Communications Technology Planning & Evaluation), and was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2018R1D1A1A09081759).

COMPETING OF INTERESTS

The author declares that there are no competing interests regarding the publication of this paper.

AUTHOR' CONTRIBUTION

The author is a sole author of this work and ES (i.e., participated in the design of the study and performed the statistical analysis).

AVAILABILITY OF DATA AND MATERIAL

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