A Cooperative Game based Spatial Correlation-aware Resource Allocation for Narrowband Internet of Things

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Abstract

In this paper, the problem of resource allocation for IoT devices in the NB-IoT network is studied where the NB-IoT eNodeB (NB-IoT eNB) in the network allocates the radio resource for enabling the uplink communication. The key challenge of the resource allocation problem is to ensure not only fairness but also efficiency in terms of allocating radio resource to the IoT devices considering data correlation. Therefore, in this paper, we exploit the spatial correlation of the NB-IoT devices and propose a cooperative game approach, bankruptcy game, for radio resource allocation for Narrowband Internet of Things (NB-IoT). The proposed game framework is able to provide both efficiency and fairness while allocating the radio resource for a massive number of IoT devices. In the simulation, we show that the proposed approach can significantly improve the radio resource allocation efficiency compared to the greedy approach and also the effect of correlation in the performance gain of the proposed method under different assumptions.

1. Introduction

The traffic demand for the IoT applications [1][2] is increasing exponentially over the years. As a result, the IoT devices require innovative and dedicated wireless technology so that the IoT applications can operate seamlessly with better connectivity. Hence, the Narrow band Internet of things (NB-IoT) radio technology is designed specifically for the IoT devices by the 3rd Generation Partnership Project (3GPP) [3]. The NB-IoT technology can provide significant benefits to the IoT device and applications in terms of coverage, power efficiency, and massive connectivity. Moreover, the NB-IoT technology can co-exist with the existing LTE network through different deployment options. However, the radio resource in the licensed wireless environment is scarce and therefore, requires efficient allocation to enable massive IoT connectivity. Moreover, the resource allocation policy should not only consider the resource availability but also need to consider efficiency and fairness where the spatial correlation of the IoT data should be exploited provided with a massive number of IoT devices. As a result, the heterogeneous IoT devices can be energy efficient and also can get better connectivity which is the core concern in the IoT ecosystem [4].

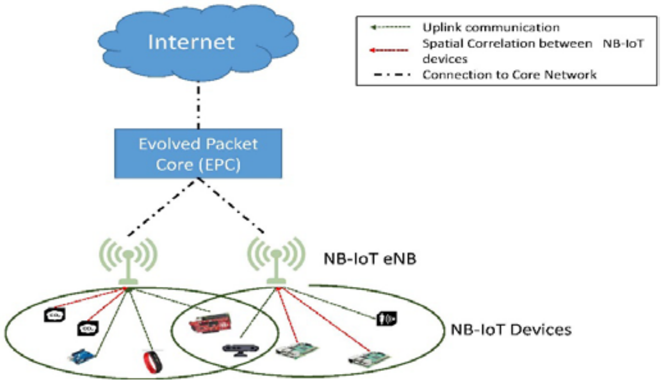

Figure 1 Proposed system model

In [5], the authors provided an enhanced system acquisition for NB-IoT focusing on the key technology of machine type communication (MTC). In [6], the authors proposed a scheme that can enable small data transmission to the NB-IoT system. In [7], the authors provided a matching based solution for IoT applications that enables cooperative node pairing. However, none of the works has exploited the correlation of the IoT data observation while allocating scarce radio resource to a massive number of IoT devices which is proven to be inefficient [8]. Therefore, in this paper, we propose a cooperative game framework, bankruptcy game, that exploits the spatial correlation of the IoT devices during resource allocation that ensures efficiency and fairness for NB-IoT radio resource usage.

2. Network and Data Correlation Model

In Fig. 1, we consider an uplink scenario where a NB-IoT network comprised of f number of NB-IoT NB-IoT eNodeBs $F=\{1,\dots,F\}$. Each of the NB-IoT eNodeBs $f \in F$ has r number of schedulable resource unit $R=\{1,\dots,R\}$ where a dedicated *physical resource block (PRB)* is allocated for the NB-IoT device access. There is also a set of i number of NB-IoT devices $I=\{1,\dots,I\}$. Moreover, the NB-IoT physical resource block is deployed in the existing LTE infrastructure as in-band deployment. Therefore, we assume that there is no interference between the LTE user devices and the NB-IoT user devices. In this scenario, the achievable uplink capacity can be calculated as,

$$C_{f,i}^{r}(\beta_i) = \beta_i \cdot \log_2\left(1+\frac{\rho_{f,i}\ \alpha_{f,i}}{\sigma^2}\right), \tag{1}$$

where β_i is the bandwidth demand of i to the NB-IoT PRB, $\rho_{f,i}$ is the is the uplink transmission power of the NB-IoT devices, $\alpha_{f,i}=\frac{1}{\Delta_{f,i}^{\epsilon}}$ is the channel gain where $\Delta_{f,i}^{\epsilon}$ is the distance and ϵ is the path loss exponent, and σ^2 is the noise power. The packet success rate of the NB-IoT devices for transmitting with the capacity $C_{f,i}^{r}$ can be calculated as,

$$\omega_{f,i} = (1-P_{f,i}^{r}(\rho_{f,i}))^{C_{f,i}^{r}(\beta_i)}, \tag{2}$$

where $P_{f,i}^{r}(\rho_{f,i})$ is the bit-error-rate from NB-IoT device to its serving eNodeB for a transmission power $\rho_{f,i}$. For a given eNodeB, it serves a subset of NB-IoT devices and therefore, each NB-IoT device experience wireless access delay which can be calculated as,

$$\tau_{f,i}^{r} = (|I_f|-1)\cdot\gamma, \tag{3}$$

where $|I_f|$ is the number of serving NB-IoT devices of an eNodeB and γ is the transmission duration. For a NB-IoT device we calculate the utility function as,

$$U_i(\beta_i,f,r) = \delta_i \cdot \frac{C_{f,i}^{r}(\beta_i)\cdot\ \omega_{f,i}}{\tau_{f,i}^{r}} + (1-\delta_i)\ \varphi_{i,|I_f|} \tag{4}$$

The utility function in (4), δ_i is the weighting parameter used by the NB-IoT devices to balance between the impact of correlation factor on the overall decision of the NB-IoT device. Therefore, the NB-IoT device can balance between the benefit of allocation with the eNodeB which is the error free transmission capacity and the associated wireless access delay. In the second part, the correlation $\varphi_{i,|I_f|}$ between i and the set of allocated NB-IoT devices I_f of f. In this paper, we have adopted the power exponential model [10] which is widely used for measuring the data correlation between the spatially deployed sensors. The model uses exponential autocorrelation function for calculating the correlation factor between the observations from sensor sources.

3. Bankruptcy Game for Spatial Correlation-aware Resource Allocation

In order to solve the problem of spatial correlation-aware resource allocation problem, we propose a cooperative game theoretic approach, bankruptcy game [9]. We assume that, different NB-IoT devices transmits the data observations where the number of requested physical resource units are different. The resource access request is then handled by the eNodeBs fairly. The total size of the PRB at the eNodeBs are fixed β_f^{max} where the requirement of the NB-IoT devices are $\underset{\beta}{\rightarrow}$. The characteristics function is then defined as,

$$\vartheta(S) = \max\left(0, U(\beta_f^{max}) - \ \textstyle\sum_{i\ \in\ I_f - S}\beta_i\right) \tag{5}$$

The equation (5) evaluates the coalition S where $\beta_i \in \beta$ is the set of pure strategies of the player i and $U(\beta_i)$ is the utility function in (4) for player choosing the strategy β_i. The coalition value is the part of the benefit that remains after assigning the aggregated resource requests in $I_f - S$. In case of the bankruptcy game, the fair allocation of resources is defined using the Shapley value as,

$$\phi_i(v) = \textstyle\sum_{S\subset\mathcal{I}_f} \frac{(|S|-1)!(i-|S|)!}{i!}(v(S)-v(S-i)) \tag{6}$$

In (6), the Shapley value provides Pareto efficiency in

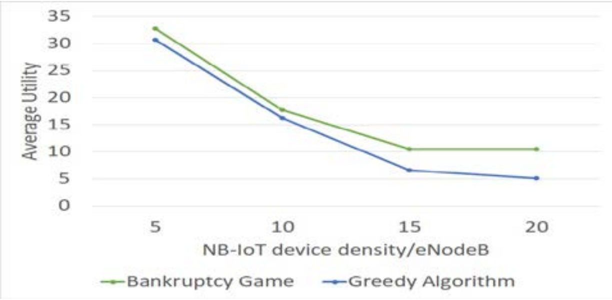

Figure 2 Average utility under different assumptions

correlation-aware resource allocation.

4. Simulation Results

In the simulation, we consider $F = 5$ where the number of NB-IoT device density is varied between 5 to 20. The demand of the NB-IoT devices are uniformly distributed between 1 to 5. The capacity of the NB-IoT carrier is 180 kHz. The factor δ in (4) is varied at different levels [0.3 0.6 0.9]. The thermal noise power spectral density is set to -175 dBm/Hz.

In Fig (2), we compare the performance of the proposed bankruptcy game based approach and the greedy approach. The greedy approach does not consider correlation level between the observations and allocate resources randomly. The proposed bankruptcy game based approach significantly outperforms the greedy approach as the number of Nb-IoT device increases per eNodeB. The performance of the methods is close to each other. However, the performance gap increases as the density increases. Moreover, the proposed approach allocates resource to more devices which produce significant observations than the greedy approach. In Fig (3), the performance of the proposed bankruptcy game based solution is evaluated based on different weighting parameter in (4). We calculate the Jain's fairness index based on the bankruptcy game based resource allocation. When the δ parameter increases, the NB-IoT device put more weight on the overall decision of the allocation process than the correlation factor in (4). Overall, the fairness decreases over the increasing number of NB-IoT device density which is the common phenomena.

5. Conclusion

In this paper, we have proposed a bankruptcy game based solution for radio resource allocation that exploits the spatial correlation between the NB-Iot devices in the NB-IoT network. We have performed the performance evaluation of the proposed game which shows significant improvement in terms of fairness and efficiency.

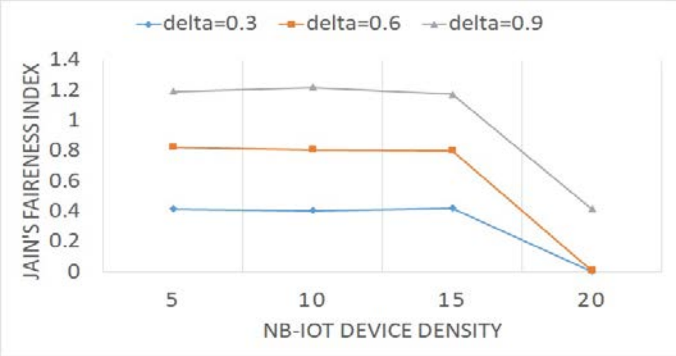

Figure 3 Jain's fairness index under different weighting parameters and density

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