CASH: A Channel Assigner Algorithm for Heterogeneous Devices in Smart Homes

Francisco R. P. da Ponte,
Rafael L. Gomes, Joaquim Celestino Jr.
State University of Ceará (UECE), Brazil
E-mail: {rodrigo.parente,
rafaellgom, celestino}@larces.uece.br

Walisson F. Pereira
State University of Vale do Acaraú (UVA), Brazil
E-mail: walisson.pereira@uvanet.br

Nelson L. S. da Fonseca
University of Campinas (UNICAMP), Brazil
E-mail: nfonseca@ic.unicamp.br

***Abstract*—In recent years, the growth of the Internet of Things (IoT) paradigm popularized the application of heterogeneous wireless devices in the residential environments, emerging the concept of Smart Homes (SHs). SHs are houses equipped with different smart devices that automate most of daily activities. These smart devices suffer a serious coexistence problem, since they all use the 2.4 GHz ISM band for communication. Within this context, this paper presents the *CASH* algorithm to minimize the interference in SH environments through suitable wireless channels assignment, mitigating the coexistence problem. The results suggest that the proposed algorithm reduces the total interference, as well as maximizes the packet delivery when compared to existing approaches.**

***Index Terms*—Internet of Things, Smart Homes, Wireless Channel, Cross-technology Interference**

I. Introduction

The popularization of smart devices provided an easy way to yield intelligence to the home environment. These devices vary in size and purpose, and can be used to automate several daily tasks, bringing more comfort and safety to the users. The conventional homes turned into smart homes, which are homes equipped with a wide variety of smart devices that communicate with each other, using the Wireless Home Network (WHN) communication technology, to achieve a common goal [1]. In general, the smart devices use the same frequency range to communicate, which is the 2.4 GHz ISM (industrial, scientific and medical). Due to this fact, the WHN suffers serious coexistence problems that affect Quality of Service, especially the reliability and latency of users applications [2].

A typical smart home environment is composed of heterogeneous devices that use different wireless technologies to communicate. In this paper, we focus on three technologies [2]: the 802.11 standard (popularly known as Wi-Fi); the IEEE 802.15.4 standard (whose most popular implementation is the Zigbee; and the 802.15.1 standard (also known as Bluetooth). Theses heterogeneous devices can be small sensors and actuators that form a Wireless Sensor Network (WSN), as well as usual devices, such as smartphones, tablets, TV, etc.

Those communication technologies mentioned before split the spectrum into channels with different bandwidths. When two devices using overlapping channels start using the medium at the same time, there is a mutual interference which causes the coexistence problem. The result is an increase in the number of collisions and lost packets [3].

The use of the CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) MAC protocol and the Adaptive Frequency Hopping (AFH) technique are examples of approaches that can be used to reduce the coexistence problems. However, those solutions can only be used for a particular type of communication technology because of specific characteristics, like bandwidth and transmission power [4]. Therefore, the coexistence of heterogeneous devices with the same frequency, but using different communication technologies is still an open issues in WHNs.

Within this context, this work presents the Channel Assigner for Smart Home (*CASH*) algorithm to assign channels to the different wireless devices in a smart home to mitigate the interference problem. The proposed algorithm takes into account the overlapping channel, the transmit power, and the signal attenuation to measure the interference of the smart home environment. The *CASH* algorithm aims to minimize the interference suffered by each wireless device caused by the coexistence problem. The experiments performed suggest that *CASH* algorithm overcomes the existing solutions.

This paper is organized as follows. Section II provides a background on wireless technologies applied in smart homes, while Section III describes the *CASH* algorithm and how it chooses the channels that minimizes the interference between the devices. Section IV discusses the results obtained in the experiments performed. Finally, Section V summarizes the paper and presents some future work.

II. Background

The most popular technologies used in smart homes are Wi-Fi, Zigbee and Bluetooth, that use the 2.4 GHz ISM band to communicate, and are the technologies considered in this paper. Moreover, each technology divides the band into channels and has specific characteristics regarding the size of each channel and the spacing between them. These technologies have singular characteristics [2]:

978-3-903176-15-7 © 2019 IFIP

- Wi-Fi is widely used by applications that require high transmission rates. Wi-Fi has 13 overlapped channels, with a bandwidth of 22 MHz. Among this channels, there are at most three that do not overlap at any given time, that can be any three channels that are five channels apart from each other, for example, 1, 6 and 11.
- Zigbee (IEEE 802.15.4) is commonly used by home automation devices, where these devices have a limited amount of power and a short transmission range. Unlike Wi-Fi, the Zigbee has 16 non-overlapping channels. Each channel has 2 MHz of bandwidth and is 3 MHz apart from each other.
- Bluetooth (IEEE 802.15.1) is applied by devices that perform peer-to-peer communication for transferring files or small data in low range scenarios. Similarly to Zigbee, Bluetooth has 39 non-overlapping channels, with 1 MHz of bandwidth and each channel is 1 MHz away from an adjacent channel.

III. Proposal

This section presents the Channel Assigner for Smart Home (*CASH*) algorithm that can be used to solve the problem of channel assignment between heterogeneous devices. In smart homes, the proposed algorithm finds the most suitable configuration of channels that minimize the interference suffered by the wireless devices, using a model to calculate the interference between them.

A. Interference model

The interference model calculates the interference between two devices and it's used by the proposed algorithm (described in Subsection III-B) to minimize the total amount of interference a device suffers. The model applied in this paper was proposed previously by the authors in reference [5] and it is shown in Equation (1), where the following notation is used:

- $I_{i,j}^{z,m}$ is the interference that the device i using channel z suffers from a device j using channel m when both devices start transmitting simultaneously.
- P_j^m is the nominal power (dBm) that device j emits its wireless signal by m channel.
- $w^{z,m}$ is the amount of the interference that channel m causes to channel z. This value is the ratio of overlapped frequency of channels z and m.
- $PL(d)$ is the signal attenuation on the distance d to 2.4 GHz operating frequency.

$$I_{i,j}^{z,m} = \frac{w^{z,m} \times P_j^m}{PL(d)} \quad (1)$$

B. Channel Assignment Algorithm

This subsection details the *CASH* algorithm, which is used to choose the set of channels that minimize the amount of interference experienced by the wireless devices in a WHN. *CASH* is a deterministic greedy algorithm, which starts with a random configuration and interactively chooses the channels that minimize the total amount of interference. An overview of our algorithm is presented in Algorithm 1 and 2 and the notation used is summarized in Table I.

TABLE I
NOTATION

SYMBOL	DESCRIPTION
$\mathcal{A}$	set of AP and its configuration
$\mathcal{D}$	set of devices and its configuration
$\mathcal{B}$	holds a copy of the best configuration for the devices
C_j	the set of channels that the AP j can use
I_{best}	best global measure of interference
I_{curr}	current measure of interference
I_{local}^{best}	best local interference

We divided the proposed algorithm into two parts to improve the explanation of *CASH*. Algorithm 1 is responsible for performing a preprocessing of the devices composing the scenario and to invoke Algorithm 2, which is responsible to choose the channel configuration that minimizes the total amount of interference in the WHN.

In Algorithm 1, from line 2 to 5, we initialize the configuration of AP antennas by choosing randomly a channel for each one. Later, between lines 6 and 9, the devices are assigned to an AP antenna taking into account the AP congestion. In each iteration, the AP which has fewer devices connected to is chosen. This ensure that the number of devices connected to any AP is uniform, which prevents an area from experiencing higher interference than others (a load balance approach). The initialization stage is finished with $\mathcal{B}$, at line 10, receiving the generated configuration, and the amount of interference suffered by devices being calculated and saved in both I_{best} and I_{curr}, at line 11. The *calcInter* function uses the model presented in the subsection III-A to calculate the interference between the set of devices or APs.

From line 12 to 19, the algorithm iterates for two times the number of devices in the scenario. It was observed, through a series of experiments, that after a certain number of iterations the value of I_{best} was no longer being updated. Therefore, we set the loop at line 12 to iterate for $2 \times |\mathcal{D}|$.

At line 13, the *channelChooser* function (which is explained in Algorithm 2) is called and returns the best channel configuration found for the set $\mathcal{A}$. In line 14, the interference between all devices is calculated and attributed to I_{curr}. In line 15, the algorithm compares if the value of I_{curr} is lesser than I_{best}, if true, $\mathcal{B}$ is updated with the new configuration for $\mathcal{A}$ and $\mathcal{D}$, and I_{best} gets the value of I_{curr}. Finally, in line 20, we return $\mathcal{B}$ that at this point has the best configuration found for the APs and devices.

Regarding the search for channels configuration, the Algorithm 2 chooses the most suitable AP channel configuration (based on the interference model explained in Subsection III-A). First, it assigns a set of random channels to AP antennas, and after it calculates and saves in I_{local}^{best} the amount of interference suffered by APs. Secondly, the algorithm iterates comparing each pair of AP antenna configuration and testing if any new channel reduces the amount of interference suffered

Algorithm 1: CASH algorithm

```
Input: A, D
Output: B
begin
    foreach j ∈ A do
        z ← a random channel from C_j;
        set channel z to AP j;
    end
    foreach i ∈ D do
        j ← get the least congested AP;
        connect the device i to the AP j;
    end
    B ← A + D;
    I_best ← I_curr ← calcInter(D);
    for count ← 1 to (2 × |D|) do
        A ← channelChooser(A);
        I_curr ← calcInter(D);
        if I_curr < I_best then
            B ← A + D;
            I_best ← I_curr;
        end
    end
    return B;
end
```

Algorithm 2: channelChooser

```
   Input: A
   Output: A
1  begin
2      Assign random channels to APs ∈ A;
3      I_local^best ← calcInter(A);
4      foreach j ∈ A do
5          foreach g ∈ A do
6              if AP j type = AP g type and j ≠ g then
7                  bestChannel ← channel used by AP g;
8                  foreach z ∈ C_g do
9                      set channel z to AP g;
10                     I_curr ←calcInter(A);
11                     if I_curr < I_local^best then
12                         I_local^best ← I_curr;
13                         bestChannel ← z;
14                     else
15                         set channel bestChannel to AP g;
16                     end
17                 end
18             end
19         end
20     end
21     return A;
22 end
```

by APs. Finally, the algorithm returns the best configuration it could find.

In a more thorough explanation, the Algorithm 2, in line 2, assigns a set of random channels to the APs. In line 3, the value of the interference suffered by the APs is assigned to the variable I_{local}^{best}. From line 4 to line 20, we have two nested *fors*, in which we loop through $\mathcal{A}$ comparing every AP. In line 6, the algorithm checks if the APs j and g are of the same type (i.e. if they use the same communication technology) and if they are different.

From line 8 to 17, the algorithm loop through the channels that can be assigned to the AP g ($\mathcal{C}_g$). In line 9, we assign the channel z to AP g ($z \in \mathcal{C}_g$). In line 10, we calculate and assign the new interference value to the variable I_{curr}. In line 11 we check if the value of I_{curr} is less than the value of I_{local}^{best}. At line 12, I_{local}^{best} is given the value of I_{local}. In line 13, $bestChannel$ receives the value of z. If the conditional is evaluated as false, at line 15, we assign the initial channel of g to $bestChannel$.

The *CASH* algorithm has a different approach than the previous work presented in [5], which minimizes the interference from the perspective of the devices. The proposed algorithm focus on the minimization of the interference by the APs, since the number of APs is fewer than the number of devices and the number of comparisons made will be less.

The complexity of the algorithm can be represented by $\mathcal{O}(|\mathcal{D}| \times |\mathcal{A}|^2 \times |z|)$, where $\mathcal{D}$ is the set of devices, $\mathcal{A}$ is the set of APs and z are the channels. Considering that the number of channels is constant, we can say that the complexity of the algorithm is $\mathcal{O}(|\mathcal{D}| \times |\mathcal{A}|^2)$.

IV. Performance Evaluation

A. Scenario Configuration

The experiments were performed in the OMNeT++ simulator[1], using the INET framework[2] to simulate a wireless network of heterogeneous devices as in a Smart Home. All the characteristics of the scenarios (physical space, network traffic, wireless technology proportion, etc) were based on the the description of smart homes provided by reference [1].

Eight scenarios were defined containing a different number of wireless devices and access points (each one executed 50 times with a duration of 15 minutes). The number of devices variated (7, 10, 12 and 15 devices, where 40% of them use Wi-Fi, 50% of devices use Zigbee, and 10% of devices use Bluetooth) using 2 APs our 4 APs. The size of the physical space was a square of 50×50 meters. The position of devices and access points were randomly distributed in each performed simulation (no mobility configured).

Regarding to traffic generation, each device sends a UDP packet, with size of 500 bytes every 1 ms. In that way, we have a saturated network, where the difference read in the amount of lost packets is a direct reflection of the amount of interference in the environment.

We compared the results obtained with our previous channel assigner based on a MILP approach [5], called *Channel*

[1]https://omnetpp.org/
[2]https://inet.omnetpp.org/

Assigner. Additionally, the experiments compare the results of the proposed algorithm with the scenario where every AP is configured using the same channel, as a standard factory configuration; and a scenario where the AP channels are randomly chosen (uniformly).

B. Results

The experiments evaluated the following performance metrics: (*i*) Interference (Figure 1), which is the total amount of interference experienced by the devices in the environment; and, (*ii*) Loss percentage (Figure 2), representing the average number of packets transmitted that were not delivered to the destination.

Figure 1 shows the interference observed when using the channels proposed by the different channel assignment techniques. As can be seen, the channel assigner [5] obtained the best results for both scenarios, followed closely by the algorithm proposed in this work (*CASH*). The use of random channels proved to be good for scenarios with a few devices, but with the increase in the number of devices, the interference increased considerably. In the same way, the utilization of the same channels by all devices was impractical.

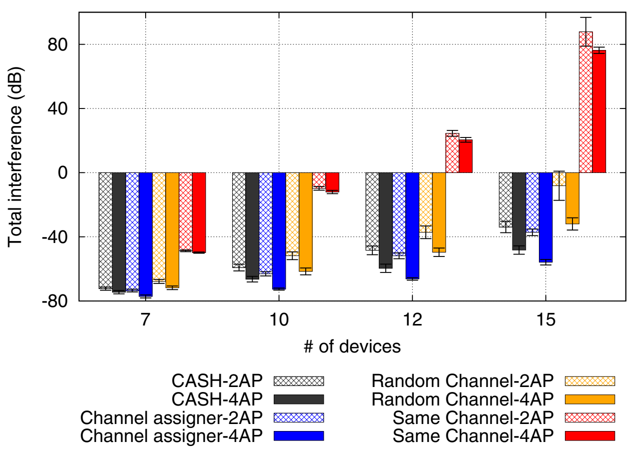

Fig. 1. Interference: 2 and 4 APs scenarios.

The usage of *CASH* resulted in an average improvement of 30% to the use of random channels and 70% to the use of the same channels, in the scenario with two APs. When compared to the channel assigner [5], it was possible to observe an increase in the average of 3dB in total interference. For the scenario composed of 4 APs, the algorithm was, in average, 30% better than the use of random channels and 80% better than the use of the same channels. Similarly to the 2 APs scenario, the proposed algorithm was worse than the channel assigner [5], with an average increase of 5dB in the total amount of interference.

That is because the proposed mechanisms use the interference model (explained in Subsection III-A) to find the set of channels that minimizes the interference suffered by the devices in the environment. Thus, as expected, both MILP and the *CASH* algorithm have the smallest interference values. Unlike other approaches, that use a random configuration (which may be a good solution) and the one that uses the same channels (which will always have the worst values).

Figure 2 presents the percentage of lost packets in the scenarios with 2 APs and 4 APs. We analyzed the number of packets that were sent by the devices and received by the APs, to calculate the percentage of packet loss. This strategy was taken because some approaches (due to the protocol MAC) end up transmitting fewer packets than others, so just the amount of packets loss would not represent the actual scenario.

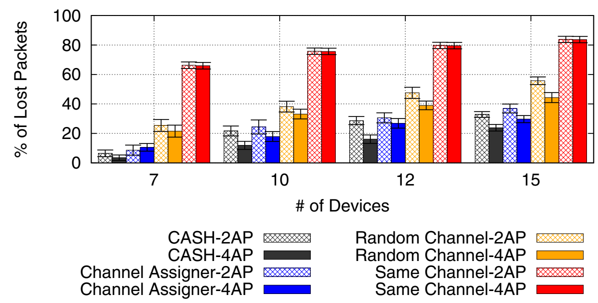

Fig. 2. Percentage of lost packages in a 4 AP scenario.

As expected, the *CASH* algorithm and channel assigner [5] presented the lower number of lost packets. The proposed algorithm for the scenario with 2 APs lost on average 2% fewer packets than channel assigner [5], 15% less than the use of random channels and 45% when using the same channels. For the scenario with 4 APs, the values were 4% for the channel assigner, 12% for the use of random channels and 50% for the use of the same channel.

V. Conclusion

The huge amount of heterogeneous devices that uses the 2.4 GHz band can cause serious problems of interference especially in smart homes. This work proposes an algorithm capable of select a set of channels that minimize the total interference suffered by these devices, considering the interference factor of overlapping channels, the transmission power of the devices and the attenuation of the signal of the environment to calculate the interference. The results shows that the algorithm was able to minimize the interference in all scenarios and delivered more packages with a lower dropped percentage, than other approaches.

For future work, we intend to make the algorithm dynamically react to the ingress and egress of devices in the network, so that it recalculates the best channels every time a change is detected. Enabling the network to have the best configuration at any given moment.

Acknowledgment

The authors would like to thank FUNCAP, FAPESP, CAPES and CNPq for financial support, and IBM for providing the CPLEX tools.

REFERENCES

[1] B. L. R. Stojkoska and K. V. Trivodaliev, "A review of internet of things for smart home: Challenges and solutions," *Journal of Cleaner Production*, vol. 140, pp. 1454–1464, 2017.

[2] R. Natarajan, P. Zand, and M. Nabi, "Analysis of coexistence between ieee 802.15. 4, ble and ieee 802.11 in the 2.4 ghz ism band," in *Industrial Electronics Society, IECON 2016-42nd Annual Conference of the IEEE*. IEEE, 2016, pp. 6025–6032.

[3] A. Mishra, V. Shrivastava, D. Agrawal, S. Banerjee, and S. Ganguly, "Distributed channel management in uncoordinated wireless environments," in *Proceedings of the 12th annual international conference on Mobile computing and networking*. ACM, 2006, pp. 170–181.

[4] E. Coronado, R. Riggio, J. Villalón, and A. Garrido, "Wi-balance: Channel-aware user association in software-defined wi-fi networks," in *NOMS 2018-2018 IEEE/IFIP Network Operations and Management Symposium*. IEEE, 2018, pp. 1–9.

[5] F. R. P. d. Ponte, K. L. A. de Almeida, R. L. Gomes, J. Celestino, W. F. Pereira, and N. L. S. d. Fonseca, "Wireless channel assignment in smart home," in *2018 IEEE Symposium on Computers and Communications (ISCC)*, June 2018, pp. 00 480–00 485.