Fair Bandwidth Allocation in Wireless Network Using Max-Flow

Sourav Kumar Dandapat, Bivas Mitra,
Niloy Ganguly
Department of CSE, IIT Kharagpur, India
{sdandapat,bivasm,niloy}@cse.iitkgp.ernet.in

Romit Roy Choudhury
Department of ECE and CS,
Duke University, USA
romit@ee.duke.edu

ABSTRACT

This paper proposes a fair association scheme between clients and APs in WiFi network, exploiting the hybrid nature of the recent WLAN architecture. We show that such an association outperforms RSSI based schemes in several scenarios, while remaining practical and scalable for wide-scale deployment.

Categories and Subject Descriptors
C.2.3[Network Operations]: Network Management
General Terms
Algorithms
Keywords
Association Control, Max-Flow, Fairness

1. INTRODUCTION

Modern wireless networks, specially built for enterprises, such as airports, universities, and corporate campuses, are getting multiple APs connected to a central controller through a high speed wired backbone. The backbone allows for out-of-band communication among APs, opening up opportunities for better protocol design for association control beyond the current method of maximum Received Signal Strength Indicator (RSSI). This paper focuses on exploiting the hybrid nature of such wireless networks for improved client-AP association. Our proposal combines the information from multiple APs to augment load-balancing and connection admittance. Using the wired backbone, APs mutually communicate the presence of clients within their communication ranges. Each AP assimilates this global information and divides the network into "exclusive" and "overlapping" zones (An area covered by a specific set of APs is called a zone. A zone is called 'exclusive' if it is covered by a single AP, otherwise it is called an 'overlapping' zone.), where clients located in the exclusive zones must associate to a specific AP, while clients in the overlapping zone have a choice among two or more APs. The APs then collaboratively model the system as a graph-theoretic *max-flow problem*, and generate the optimal client-AP assignment. The assignments are communicated back to the clients and associations occur accordingly. Performance improves because the concentration of clients at specific hot-spot regions does not overwhelm a single AP. Instead, clients are distributed among different APs in the neighborhood even if the received signal strength of their links are relatively weaker.

SIGCOMM'10, August 30–September 3, 2010, New Delhi, India.
ACM 978-1-4503-0201-2/10/08.

2. FAIR BANDWIDTH ALLOCATION (FBA)

Basic Protocol: With our scheme, a client temporarily associates to an AP using RSSI-based association. As a part of the association process, the client also conveys the IDs of all APs that it has recently overheard. The AP shares this information with other APs (over the wired backbone), thereby learning about the population of clients in different zones around each AP. Using the current distribution of devices, FBA algorithm, which executes periodically, applying max-flow algorithm finds a particular client-AP association configuration.

Metrics: The metrics (JFI and PCA) which are used to evaluate FBA algorithm is elaborated next.

Jain's Fairness Index (JFI) is formally defined as

$$JFI = (\sum_{i=1}^{m} FR_i)^2 \times (m \times \sum_{i=1}^{m} (FR_i)^2)^{-1} \quad (1)$$

where FR_i is the fairness ratio of i^{th} zone (ratio of admitted device and total device), m is the total number of zones. Higher value of JFI indicates higher fairness.

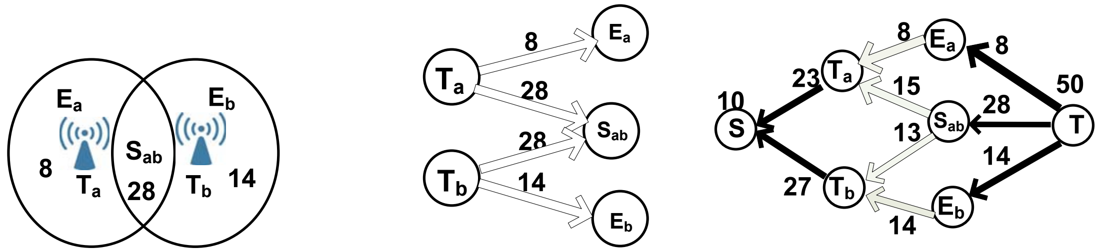
Percentage of Connection Admitted (PCA) is the percentage of devices admitted in the network where devices are admitted only when the system can offer a minimum bandwidth, configured by the system designer.

Mapping the Association Problem to a Max Flow Problem: A typical network setting (Fig. 1(a)) can be represented as a flow graph (Fig. 1(b)) where all the APs (T_a, T_b) and all the zones (E_a, S_{ab}, E_b) are realized as nodes in this graph. Edge exists between an AP node and a zone node if that AP can contribute bandwidth to that zone, and the edge capacity is representing the requirement of corresponding zone. The objective remains in maximizing the flow (admittance) of the zone-nodes; hence max flow becomes a natural choice. The problem then get reduced to a multiple source (APs), multiple sink (zones) flow problem.

Modification of Max Flow: Max Flow guarantees maximum flow (maximum number of device admittance) but does not ensure equitable distribution of flow (fairness). To make the allocation fair as well as to restrict overflow, we adapted a four-stage max flow after doing several round of experimentations. In each stage, every AP targets to utilize a fraction of its capacity. The fractions are set to 50%, 75%, 92%, 100% successively.

3. RESULTS

We perform a simulation-based experiment in order to show the effectiveness of our proposed association control protocol



(a) An instance with two APs (*Ta*, *Tb*) and three zones (*Ea*, *Eb*, *Sab*) and requirement of bandwidth of every zone. Each AP can associate at most 30 devices. RSSI may lead 28+14=42 devices trying to get associated with Tb.

(b) Mapping of the problem instance into a flow network where the edge weight indicates the potential number of devices in that zone, an AP can serve.

(c) Logical graph (S, T are logical source & sink) after four-stage of max flow. Ta (Tb) satisfies 23 (27) devices where (Ta, Sab)=15 and (Tb, Sab) =13.

Figure 1: Shows reduction of association problem to a max flow problem and the final association.

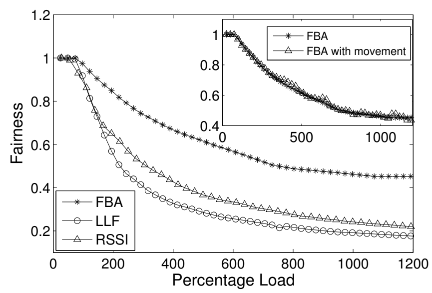


Figure 2: Fairness with varying load using 1)FBA 2)LLF 3)RSSI. Inset shows the effect of fairness due to movement on FBA.

over the traditional RSSI based approach and LLF (Least Load First[1]) based approach. We take the campus of Indian Institute of Technology (IIT) Kharagpur, India as a case study.

Traffic and Mobility Model: We have assumed the total number of devices is distributed among zones according to the power law in line with various recent studies [2]. We have assumed that 60% of the zones will be involved in movement. For convenience, we have divided these chosen zones into pairs, whereby 10% of devices from the originating zone move to the destination zone. The originating zone is chosen randomly, while a popular zone is more likely to be chosen as destination.

Benchmark Algorithms: To evaluate the performance of our proposed algorithm, we compare its performance with RSSI and LLF. In RSSI based algorithm client associates itself with AP from which it is getting the strongest signal and in LLF approach client associates itself with the AP with least load.

JFI: Fig. 2 shows that FBA is much superior to other schemes in terms of fairness. When load increases beyond 100%, fairness drops drastically for other schemes, showing FBA's hence max-flow's superiority over other ad-hoc schemes. Interestingly JFI does not degrade (It in fact increases at certain places!) with movement. This happens as we cannot ensure total optimal fairness through FBA, a slight movement of devices moves the solution out of local optima.

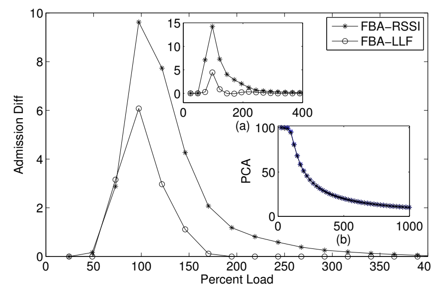


Figure 3: Shows admission difference using different schemes with power law traffic, inset (a) shows it with uniform traffic. Inset (b) shows effect of PCA due to movement on FBA.

PCA: Fig. 3 confirms that FBA algorithm also performs better than RSSI and LLF in terms of PCA. Though gain by FBA over the others is moderate (5%-10% -power law, 7%-14% -uniform), but we achieve this difference in most viable load region (50%-200%). Inset (b) shows that PCA does not degrade even when we have some movement.

4. CONCLUSION

This paper combines result from traditional graph theory with the emerging opportunities in wireless setting to target the pressing problem of association control. Initial results are promising both in terms of admittance and fairness. Future work is focused on addressing a number of important issues, including cross-AP interference, channel bit-rate, and mobility/node churn.

Acknowledgement

SKD acknowledges the financial support from Vodafone Essar.

5. REFERENCES

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