A Wireless Solution for SDN (Software Defined Networking) in Data Center Networks

Ruitao Xie, Zuneera Umair, Xiaohua Jia
City University of Hong Kong, Kowloon Tong, Hong Kong
ruitao.xie@gmail.com, zaziz3-c@my.cityu.edu.hk, csjia@cityu.edu.hk

***Abstract*—Software Defined Networking has been adopted to improve data center network efficiency. In SDN, the controllers are responsible for exchanging information with the switches to perform specific operations such as data forwarding. The transmission of control traffic usually uses networks different from data networks. However, building an additional wired network for the control traffic leads to high cabling complexity. Since a wireless network involves almost no cabling and is easy to install, we propose a wireless solution where switches make a wireless connection with controllers via wireless access points (AP). In this design, switches are divided into clusters, and an AP is placed at the center of each cluster. An important issue is to determine the minimum number of APs such that a given control traffic demand can be met. We propose an analytical model to evaluate the system throughput for possible clusterings, and an efficient algorithm to search for the optimal one. The extensive simulations demonstrate that our method can reduce cabling complexity significantly.**

I. Introduction

Software Defined Networking (SDN) can dramatically simplify the design of many applications in data centers [1], [2], such as energy saving [3], resource management [4], [5] and traffic engineering [6]. It decouples the software controlling a network from the devices that implement network functions. The decoupled network control consisting of logically centralized controllers form the Control Plane, where as the switches form the Data Plane. The control plane uses a different network from the data network. However, building an additional wired network in a data center leads to high cabling complexity, which has been identified in existing research works [7], [8]. Since a wireless network involves almost no cabling and is easy to install, we propose a wireless solution for the SDN in data center networks.

A naive method is to provide switches and controllers with wireless antennas and connect them directly. However, it would result in low throughput, since there are usually thousands of switches in a data center. Thus, instead of directly connecting, we use a set of wireless access points (AP) to provide wireless communication between the switches and the controllers. Therefore, we propose a design in which switches are divided into clusters with an AP in the center. The AP is connected to the controller via Ethernet. This architecture can improve throughput as all the switches in the data center would be divided into clusters. The main problem in this architecture is how to divide the data center into clusters with minimum number of APs and desired throughput. Thus, our problem is to use minimum number of APs to cover all switches such that a given traffic demand can be met.

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To achieve our objective, we can compute the throughput of the network with all clustering schemes, which is a non trivial problem. Therefore, we propose an analytical model that can exhaustively enumerate possible clusterings meeting the traffic demand. However, this is an inefficient approach. Therefore, we further propose a method that limits the search to a subset of clusters. Our simulations demonstrate that far fewer APs than switches are required to support control traffic, thus the proposed wireless SDN can reduce cabling significantly.

The rest of this paper is organized as follows. Section II presents the related works on using wireless technology in data centers. In Section III we propose a wireless SDN architecture and present the problem formulation. Section IV presents an analytical model to compute throughput for any clustering. Section V presents the algorithm to search for the optimal clustering. The simulations and performance evaluations are presented in Section VI. Section VII concludes the paper.

II. Related Works

We review related works and categorize them into following two groups.

SDN in Data Centers. Lots of research has been done to tackle various challenges in deploying SDN in data centers. Yeganeh *et al.* in [9] proposed several ways to tackle the scalability problem in applying SDN. Heller *et al.* in [10] investigated the controller placement problem in deploying SDN. Curtis *et al.* in [11] investigated the control granularity problem. They indicated that the fine-grained control in classic SDN brings costs. To address this issue, they proposed to let the controller maintain control over only significant flows, while let switches handle most flows. All these works do not consider the problem of designing networks for transmitting SDN control traffic, which we focus on.

Wireless Networks in Data Centers. Several works have been done to use wireless technology to augment or replace wired links in data centers. Halperin *et al.* in [7] and Zhou *et al.* in [12] proposed to use 60 GHz wireless links to augment wired links in an oversubscribed data center network, so that traffic hotspots can be alleviated. Hamedazimi *et al.* in [8]

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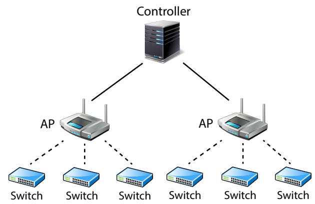


Fig. 1. Wireless SDN architecture

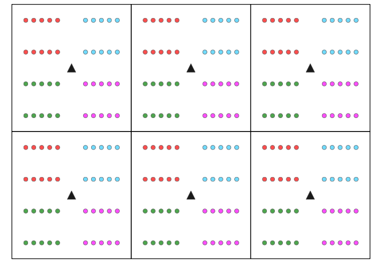


Fig. 2. An example of proposed architecture where switches (dots) connect to APs (traingles). Switches are divided into cluster and AP is placed in the center. Various colors represent different sector antennas.

proposed a data center architecture FireFly where all inter-rack links are wireless and reconfigurable. All these works use wireless links to transfer data traffic. In comparison, our work uses wireless links to transfer SDN control traffic. The data traffic is transferred between top-of-rack switches at high rate, while the control traffic is transferred between switches and SDN controllers at low rate.

III. Wireless SDN Architecture and Problem Formulation

In this section, we first present the wireless SDN architecture and explain the design rationale, and then present problem formulation. We use wireless links to connect switches and controllers to reduce cabling complexity and easy installation. Using wireless links for control traffic is feasible mainly because that the control traffic amount is low [2], [9], [11].

A. Wireless SDN Architecture

In our architecture (Fig. 1), APs are used to connect switches and controllers in a data center network environment to provide wireless communication. The switches are divided into clusters and wirelessly connect with an AP placed at the center of each cluster. Further, the APs connect the controller via Ethernet. We use CDMA as a multiple access technique so that a common frequency spectrum is used within the cluster. Also CDMA supports more switches per cluster than TDMA or FDMA [13]. We equip APs with multiple directional antennas to reduce interference within a cluster. The switches are also installed with directional antennas. Therefore, each switch would be served by a particular sector of the AP directional antenna.

In data centers, racks are regularly placed in a grid. Switches would also follow the same pattern as they are placed on top of racks. Thus, we divide the data center into rectangular shaped clusters such that each cluster has same number of switches being served by one AP. Through this approach the whole area is covered without much overlap. See Fig. 2 for an example.

The main issue in our architecture is how to divide an entire data center area so that we have minimal number of APs. However, in CDMA systems, the fewer the APs are, the lower the throughput is. Thus, given the amount of control traffic, our task is to use minimum number of APs to cover all switches in the data center, such that the traffic demand can be met.

B. Problem Formulation

A data center network is divided into square shaped clusters as illustrated in Fig. 2. Each cluster contains a set of switches and an AP associated to it. The position of each switch is denoted by the coordinate (x, y), where x is the row and y is the column of the location of the switch respectively. Each position in the data center defined by the tuple (x, y) has one switch. Therefore, a clustering scheme is defined by the tuple (N_r, N_c), where N_r is the number of rows and N_c is the number of columns in the cluster. The data rate between a switch and an AP, denoted by $r(x, y)$, should be no less than the traffic demand of each switch D. So, the constraint is:

$$r(x, y) \geq D \tag{1}$$

Thus, our problem is to find the optimal clustering scheme (N_r, N_c), such that the constraint defined in Eq. 1 is met.

IV. Analytical Model for Throughput

In this section, we propose an analytical model to compute the throughput under any clustering.

A. Throughput

A network after clustering can be represented as a directed graph $G = \langle V, E\rangle$, where V are nodes consisting of S switches and A APs, i.e. $V = S \cup A$. E are the links connecting switches to their associated AP, that is, $E = \{e_{ij},\ \forall s_i \in S,\ s_i$ is associated to $a_j \in A\}$. Thus, the data rate between a switch and an AP, r, can be computed as $r = \min\{R_e,\quad \forall e \in E\}$, where R_e denotes the maximum data rate on link e.

Recall that CDMA is used in our proposed design. In CDMA, the same frequency is used for communication. However the code for each transmitter is different and that code is correlated with the signal to decode or encode it. A least level of bit energy-to-noise density ratio (*i.e.*, E_b/N_0) should be met in order to successfully decode the signal. The E_b/N_0 at the receiver is calculated as $E_b/N_0 = \text{SINR} \cdot (W/R)$, where SINR is Signal-to-Interference-and-Noise Ratio at the receiver, W is the system's bandwidth and R is the data rate on the link. Let $(E_b/N_0)_{th}$ denote the least level of E_b/N_0 to decode the signal. Changing the notations, we have:

$$R_e = \frac{\text{SINR}_e \cdot W}{(E_b/N_0)_{th}}, \tag{2}$$

where SINR_e is the SINR at the receiver of link e. It is observed that a higher SINR can lead to a higher maximum data rate. Therefore, we need to calculate the SINR for the uplink and the downlink.

B. SINR for Uplink and Downlink

Before computing SINR, we first compute the path loss of each link as path loss impacts the SINR performance of any link. Given link e between a switch and an AP, let $H(e)$ denote the path loss of link e, and d_e be the distance between two nodes of link e. Also the gain of switch antenna is g_e^{S} and that of the AP antenna is g_e^{A}. Therefore,

$$H(e) = \frac{{d_e}^{\alpha}}{g_e^{\mathrm{S}}\, g_e^{\mathrm{A}}}, \tag{3}$$

where α is the path loss exponent, ranging from 2 to 4 [14].

For an omni-directional antenna, g_e^{S} or g_e^{A} equals to 1. For a directional antenna, the gain can be modeled using the Cosine antenna model, that is, it is maximum in the antenna's orientation, and decreases in other directions. Let $\phi_e^{\mathrm{S}} \in (-\pi, \pi]$ denote the horizontal angle between the connection of link e and the antenna orientation of the switch, which is directed to its AP. Then, we have $g_e^{\mathrm{S}} = \cos^{\sigma}(\frac{\phi_e^{\mathrm{S}}}{2})$, where σ is the parameter determining the beamwidth of a switch antenna. Similarly, let $\phi_e^{\mathrm{A}} \in (-\pi, \pi]$ denote the horizontal angle between the connection of link e and the orientation of the AP, then $g_e^{\mathrm{A}} = \cos^{\tau}(\frac{\phi_e^{\mathrm{A}}}{2})$, where τ is the parameter determining the beamwidth of each AP. Replacing g_e^{S} and g_e^{A} in Eq. 3 , the path loss can be computed as

$$H(e) = \frac{{d_e}^{\alpha}}{\cos^{\sigma}(\frac{\phi_e^{\mathrm{S}}}{2}) \cos^{\tau}(\frac{\phi_e^{\mathrm{A}}}{2})}. \tag{4}$$

Now, we compute the SINR. By definition, the SINR is the ratio between Signal Power and Noise Power. Generally, the SINR is given as:

$$\mathrm{SINR} = \frac{P_{\mathrm{S}}}{P_{\mathrm{N}} + P_{\mathrm{I}}}, \tag{5}$$

where P_{S} is the signal power, P_{N} is the thermal noise and P_{I} is the Interference Power. Given uplink e_{ij} (solid line in Fig. 3(a)) from s_i to its associated AP a_j, we will compute SINR_{ij}. Let P_{ij} denote the signal strength of s_i at a_j. To calculate the interference power, we need to consider the switches $s_k \epsilon S$ that also interfere. Therefore the interference power $P_{\mathrm{I}} = \sum_{s_k \in S} P_{kj} - P_{ij}$, where P_{kj} denote the signal strength of switch s_k at a_j.Thus, we have

$$\mathrm{SINR}_{ij} = \frac{P_{ij}}{P_{\mathrm{N}} + \sum\limits_{s_k \in S} P_{kj} - P_{ij}}. \tag{6}$$

In order to achieve an overall good performance, the signal strength of individual APs to their respective switches should be ideally at the same level. To achieve this, CDMA uses a power control method in which the transmit power of switches are adjusted carefully so that the received power at the AP from associated switches remains equal, denoted by P. Let S_j denote the set of switches associated to antenna a_j. With power control, for any $s_k \in S_j$, P_{kj} equals to P, thus we have

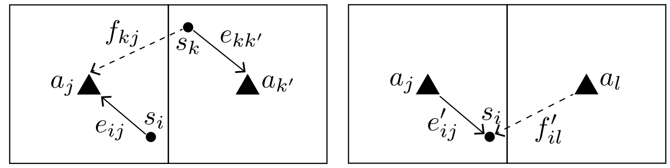


Fig. 3. the signal links (solid line) and interference links (dashed line) between switches (dots) and AP antennas (triangles). (a) is for uplinks; (b) is for downlinks.

$$\sum_{s_k \in S_j} P_{kj} = \sum_{s_k \in S_j} P = m_j \cdot P, \tag{7}$$

where m_j is the number of switches in S_j.

For any other switch $s_k \in S \setminus S_j$, its interference strength at a_j (that is P_{kj}) is also computed. Let f_{kj} (dashed line in Fig. 3(a)) denote the interference link from s_k to a_j, and $e_{kk'} \in E$ (right solid line in Fig. 3(a)) denote the signal link from s_k to its associated AP antenna $a_{k'}$, then we find the power from any other switch s_k to the AP j as:

$$P_{kj} = \frac{P_k^{\mathrm{T}}}{H(f_{kj})} = \frac{H(e_{kk'})}{H(f_{kj})} P, \qquad \forall s_k \in S \setminus S_j, \tag{8}$$

where the first part of the equation is obtained from the definition of path loss, and the second part is obtained because the transmit power of s_k (P_k^{T}) is adjusted such that the received power at the destination of $e_{kk'}$ is P. Combining above two equations, we obtain:

$$\begin{aligned} \sum_{s_k \in S} P_{kj} &= \sum_{s_k \in S_j} P_{kj} + \sum_{s_k \in S \setminus S_j} P_{kj} \\ &= m_j \cdot P + \sum_{s_k \in S \setminus S_j} \frac{H(e_{kk'})}{H(f_{kj})} P. \end{aligned} \tag{9}$$

Replacing $\sum\limits_{s_k \in S} P_{kj}$ in (6) with above equation and P_{ij} with P; and further solving it analytically we obtain

$$\mathrm{SINR}_{ij} \approx \frac{1}{m_j - 1 + \sum\limits_{s_k \in S \setminus S_j} \frac{H(e_{kk'})}{H(f_{kj})}}, \tag{10}$$

where P_{N} is negligible and always ignored. We can see that all uplinks in the same sector have the same SINR.

Next, we analyze SINR for downlinks. With reference to Eq. 5, given downlink e'_{ij} (solid line in Fig. 3(b)) between switch s_i and its associated AP a_j, we will compute SINR'_{ij}. Let P'_{ij} denote the received power at s_i on link e'_{ij}, then we have $P_{\mathrm{S}} = \lambda_{ij} P'_{ij}$, where λ_{ij} is the portion of P'_{ij} which is for s_i. This is because, as each AP antenna transmits to multiple switches in its sector simultaneously, P'_{ij} is the linear combination of all signals for all the switches in the same sector i.e. $\sum\limits_{s_k \in S_j} \lambda_{kj} = 1$, where S_j denotes the set of switches in the sector of a_j. The rest of received power $(1 - \lambda_{ij}) P'_{ij}$ contributes to interference.

Besides, there is interference from other AP antennas. Since other AP antennas transmit at the same time and using the same frequency spectrum, their signals bring interference to s_i. The power of this interference is $\sum_{l\neq j} P'_{il}$, that is, the total received power at s_i from all AP antennas except a_j to which s_i is connected. Thus, the total interference is $P_\mathrm{I} = (1-\lambda_{ij})P'_{ij} + \sum\limits_{l\neq j} P'_{il}$.

To find the SINR in the downlink, SINR'_{ij}, we put the values of P_S and P_I and ignoring noise power P_N in Eq. 5, we get:

$$\mathrm{SINR}'_{ij} \approx \frac{\lambda_{ij}P'_{ij}}{(1-\lambda_{ij})P'_{ij} + \sum\limits_{l\neq j} P'_{il}}. \tag{11}$$

We assume all AP antennas use equal transmit power, denoted by P', then according to the path loss model, we have $P'_{ij} = \frac{P'}{H(e'_{ij})}$. Similarly, for downward interference link between s_i and a_l, f'_{il} (dashed line in Fig. 3(b)). we have $P'_{il} = \frac{P'}{H(f'_{il})}$. We put these values into Eq. 11 and solve it analytically to obtain:

$$\mathrm{SINR}'_{ij} = \frac{\lambda_{ij}}{1-\lambda_{ij}+\beta_i}, \tag{12}$$

where $\beta_i = \frac{H(e'_{ij})}{\sum_{l\neq j} H(f'_{il})}$.

Similarly, for other switches s_k under the same AP and in the same sector, the SINR in the downlink can be derived as in Eq. 10 as:

$$\mathrm{SINR}'_{kj} = \frac{1}{m_j - 1 + \sum\limits_{s_k\in S_j}\beta_k}, \qquad \forall s_k \in S_j. \tag{13}$$

It is observed that all downlinks in the same sector also have the same SINR. From above analysis, it is obtained that the SINR is fully determined by the network formed with a clustering scheme. Since the system throughput is a function of SINR, it is also a function of clustering scheme. Moreover, since the throughput is proportional to the SINR, and the SINR is inversely related to the number of switches in individual sectors, the throughput decreases as each cluster has more switches. In the next section, we will search for the optimal clustering scheme, with which the system throughput of the formed network meets the traffic demand and the number of APs is minimized.

V. Search Algorithm for Optimal Clustering

In this section, we propose an algorithm to find the optimal clustering scheme. Given the total number of switches and traffic demand, our algorithm has three major steps: 1) generate all possible clustering schemes for the given traffic demand; 2) select the clustering schemes whose shapes are close to square; 3) calculate the system throughput of every selected scheme via the proposed analytical model and exhaustively search for the optimal scheme.

Recall that a clustering scheme is defined as (N_r, N_c). Therefore, the number of switches inside a cluster is $N_r \times N_c$. However, all possible values of this are upperbounded by a value related to the traffic demand as the number of switches in one sector of the AP directional antenna, m, would relate to the SINR. If m increases, the SINR would decrease and the traffic demand may not be fulfilled.

On one hand, the SINR of any link in the network formed with any clustering scheme is no more than $\frac{1}{m-1}$, which is the SINR when the out-of-sector interference becomes zero. That is, SINR $\leq \frac{1}{m-1}$, which can be observed from the computations of SINR in (10) and (13). On the other hand, for any given traffic demand D, a least level of SINR is required as $\frac{(E_b/N_0)_{th}}{W/D} \leq$ SINR. Comparing these equations, we can derive the value of m as:

$$m \leq \frac{W/D}{(E_b/N_0)_{th}} + 1. \tag{14}$$

Thus, given K sectors in use, we have

$$N_r \times N_c \leq K \cdot \left(\frac{W/D}{(E_b/N_0)_{th}} + 1\right). \tag{15}$$

As such, the set of possible clustering schemes (denoted by C) becomes smaller, as follows,

$$C = \{(N_r, N_c) \text{ where } N_r \times N_c \leq K \cdot \left(\frac{W/D}{(E_b/N_0)_{th}} + 1\right)\}. \tag{16}$$

In order to reduce the computation, we will only evaluate a subset of clustering schemes in C. The set C will contain different cluster sizes n by varying N_r and N_c, such that $N_r \times N_c = n$. However, we select the schemes that form a nearly square shaped cluster only as long and narrow clusters would lead to low SINR and throughput (demonstrated in Section VI-D). To select the square shaped clustering schemes, we get the average width-to-length ratio of each scheme. A scheme forming a square would have the width-to-length ratio of 1, where as for long and narrow (rectangle like shape) would have a ratio of 0. Thus, we select the schemes with the largest average width-to-length ratio. For each selected clustering scheme (N_r, N_c), the system throughput can be computed via the analytical model. The number of required APs of a particular clustering scheme (N_r, N_c) can be obtained as well.

VI. Performance Evaluation

In this section, we evaluate the performance extensively and demonstrate that the wireless SDN solution is effective to reduce cabling. The cabling in our architecture comes from connecting APs to controllers via Ethernet. The fewer the APs, the less the cabling.

A. Simulation Setups

We first introduce our data center configuration, which is similar to the layout used in [12]. Its size is 87m×105m and it contains 3000 racks. As shown in Fig. 4, racks are grouped into 30×10 blocks, and each block is a row of 10 racks with no inter-spacing. Aisles separating the blocks are 3m (between

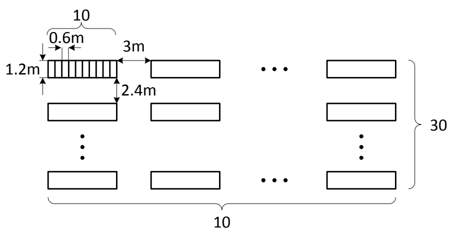


Fig. 4. The data center configuration for simulations.

TABLE I
FREQUENCY BAND AND BANDWIDTH SETTINGS (MHZ).

frequency	duplex scheme	bandwidth & band uplink	downlink
5 GHz	FDD	100 (5.170∼5.270 GHz)	100 (5.735∼5.835 GHz)
5 GHz	TDD	160 (5.170 ∼5.330 GHz)	
2.4 GHz	FDD	40 (2.400∼2.440 GHz	40 (2.450∼2.490 GHz)
2.4 GHz	TDD	90 (2.400 ∼2.490 GHz)	

columns) and 2.4m (between rows). Each rack is 0.6m in width and 1.2m in length. We assume that one switch is located and centered on the top of each rack. Our task is to connect these switches (3000 in total) to a controller using our architecture.

Next we introduce the settings of frequency bands. We simulate with two ISM bands: 5 GHz and 2.4 GHz, with Time Division Duplex (TDD) and Frequency Division Duplex (FDD) respectively. The bandwidth settings at each frequency band and for each duplex scheme are listed in Table I.

We simulate for AP antenna configurations of omni directional, 3-dB beamwidth of 40° (4 sectors) & 60° (3 sectors) respectively and switch antenna configurations of 30° beamwidth. For directional antenna, the factor σ is calculated through the Cosine antenna model as $\sigma = -\frac{3}{10\log_{10}\left(\cos\frac{\phi_{3dB}}{4}\right)}$. Therefore, σ for beamwidth 30°, 45° and 60° is 80, 36 and 20 respectively.

In addition, we set $(E_b/N_0)_{th}$ for reliable communications to 10 dB, with which BPSK or QPSK modulation can yield a BER less than 10^{-5} in AWGN channels [15]. The path loss exponent α is set to 3.

B. Evaluation of Cluster Size

To demonstrate the effectiveness of the proposed design, we evaluate the cluster size. It is defined as the average number of switches per cluster. Since some clusters near the border of the data center may have fewer switches, the average cluster size for scheme (N_r, N_c) may not consider the border switches. To do experiment, we test different control traffic demands, ranging from 0.1 to 1 Mbps. For each demand, we compute the optimal clustering scheme and obtain its average cluster size.

Fig. 5 shows the results at 5 GHz. It is observed that using directional antennas can improve the performance significantly. When switches use omni-directional antennas, the cluster size increases as APs use more concentrated directional antennas. When switches also use directional antennas, the cluster size increases further. The best case is when switches use 30° antennas and the APs use 45° antennas, at the traffic demand of 0.1 Mbps, in FDD setting, each cluster can cover 300 switches, that is, 10 (*i.e.*, 3000/300) clusters (APs) are required; in TDD setting, each cluster can cover 250 switches and 12 clusters are used. Even at the traffic demand of 1 Mbps, each cluster can cover 30 switches in FDD and 20 switches in TDD. Thus, the results demonstrate that the required APs in our method are significantly fewer than the switches to be covered, so the cabling complexity for deploying a wireless network is greatly less than that for deploying a wired alternative. Second, it is observed that as traffic demand increases, cluster size decreases, and more APs are required. This is because a larger traffic demand has a higher SINR requirement, and to meet the higher SINR each cluster has to cover fewer switches. Also, the performance of FDD is much better as compared to TDD because FDD uses more bandwidth, as shown in Table I.

We also simulate at 2.4 GHz and show the results in Fig. 6. It is observed that in the case of using the most concentrated directional antennas, at the traffic demand of 0.1 Mbps, in FDD setting, each cluster can cover as many as 125 switches and 24 clusters (APs) are required; in TDD setting, each cluster can cover 150 switches and 20 clusters are required. Even at the traffic demand of 1 Mbps, each cluster can cover around 12 switches in both settings. The cluster size at 2.4 GHz is less than that at 5 GHz due to less bandwidth, for the same reason as above. We use a minimum number of 4 switches per cluster for economical reasons.

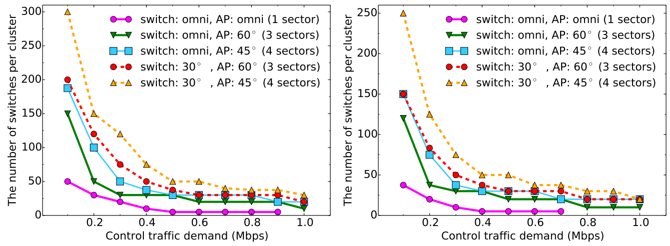
Fig. 7 shows that the computation complexity as we select the clustering schemes satisfying the traffic demand only. It can be seen that with the proposed search algorithm, the computation complexity decreases.

C. Evaluation of Throughput

We also evaluate the maximum system throughput (the achievable traffic rate between any switch and the controller) given the number of APs allowed to use in order to compare with the wired counterpart. Given a certain limit to the AP amount, among all cluster schemes whose resulted number of APs is no more than the limit, we select the one achieving the highest throughput The results are shown in Fig. 8. We can see that the maximum throughput can reach 3 Mbps when more than 300 APs (10 percent of the number of switches) are allowed to use. Thus, when the control traffic demand is greatly larger than 3 Mbps, wired SDN is probably a better choice.

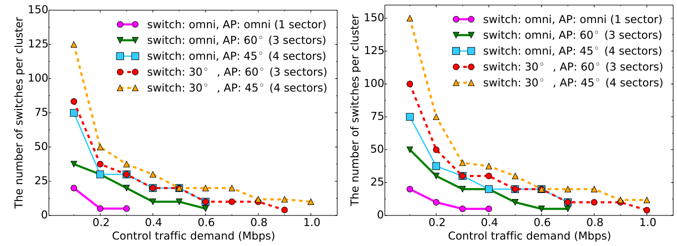
D. Factors Impacting SINR

Since, the SINR is better for square-like clustering schemes, we select the schemes with a width-to-length ratio of nearly 1 (closer to a square). Given a cluster size n, we test all possible schemes by varying N_r and N_c such that $N_r.N_c = n$ and compute SINR's. Thus, in Fig. 9, we can see that the SINR roughly increases as the width-to-length ratio increases, which means the clusters close to square lead to better SINR.



(a) (b)

Fig. 5. The number of switches per cluster at 5 GHz using different antennas for switches and APs, satisfying different control traffic demands. The angle is the 3dB-beamwidth of directional antennas. (a) is for FDD; (b) is for TDD.



(a) (b)

Fig. 6. The number of switches per cluster at 2.4 GHz using different antennas for switches and APs, satisfying different control traffic demands. The angle is the 3dB-beamwidth of directional antennas. (a) is for FDD; (b) is for TDD.

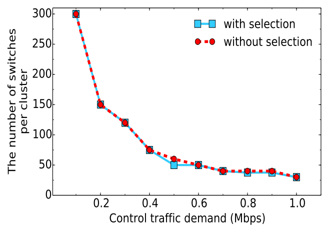


Fig. 7. Computation complexity with and without search algorithm for simulation setting of FDD at 5 GHz. APs and switches use 45○ and 30○ antenna.

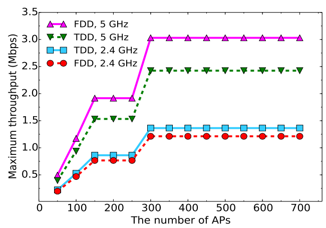


Fig. 8. The maximum achievable throughput given different number of APs allowed to use. There are 3000 switches in total. Switches use 30° antennas and APs use 45° antennas.

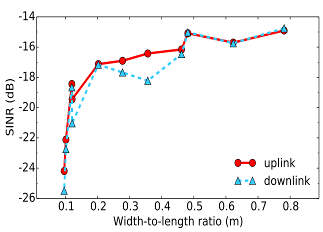


Fig. 9. The SINR for clustering schemes of different average width-to-length ratios, where the cluster size is fixed at 120. Switches use 30° antennas and APs use 45° antennas.

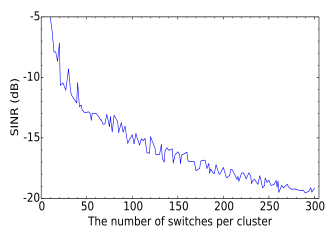


Fig. 10. The SINR for clustering schemes with different cluster sizes. Switches use 30° antennas and APs use 45° antennas for width-to-length ratio greater than 0.5.

In addition, there are some fluctuations because under some schemes switches may not be divided equally among sectors, resulting in low SINR in some sectors containing many switches.

Next, we demonstrate that SINR decreases as the cluster size increases. We select the clustering schemes with the average width-to-length ratio greater than 0.5 only. Fig. 10 shows these results.

VII. Conclusion

In this paper, we propose a wireless connectivity between switches and controllers for SDN control traffic in a data center. The switches form rectangular clusters and are connected to the APs wirelessly and the APs connect to the controller through Ethernet. Each cluster contains a single AP and a number of switches connected to it. An important issue is to find a clustering, such that a given control traffic demand can be met and the number of APs is minimized. To address the problem, we propose an analytical model to evaluate the system throughput for possible clustering schemes, and an efficient algorithm to search for the optimal one. The extensive simulations demonstrate that our method requires far fewer APs than switches. Thus, the proposed wireless architecture requires less cabling in connecting APs to controllers than the wired network.

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