Recent Advances in Broadband Wireless Access Networks

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Abstract:

Wireless is a promising approach to provide broadband Internet access to rural and remote areas. This paper covers issues on enhancing the network capacity and management, reducing the energy and the cost of deployment and application scenarios that can benefit from the wireless broadband access. Wireless Optical Broadband Access Networks, as a popular architecture, is intensively discussed over multiple sections.

Keywords:

Broadband Wireless Access (BWA), Wireless-Optical Broadband Access Networks (WOBAN), Architectural Approach, Energy Efficiency, Long Reach Access, IPTV, Mission Critical (MC)

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1. Introduction to Broadband Wireless Access

The focus of meeting the growing need for broadband access has shifted onto cover rural and remote areas with relatively lower user density and no network infrastructure [Bernardi10]. Broadband Wireless Access (BWA) is now considered a promising alternative due to the availability of low cost commodity wireless hardware, newly freed spectrum and the progress in communication technology.

Wireless Optical Broadband Access Networks (WOBAN) is a popular BWA architecture. It has a wired optical backhaul network at back end and a wireless mesh network at front end. The wireless part provides access to end users and the wired part carries the aggregated traffic from the wireless part. Such an architecture is shown in Figure 1. The optical backhaul network consists of a Passive Optical Network (PON), an Optical Line Terminal (OLT) in the Central Office (CO) that is connected to multiple Optical Network Units (ONUs) via optical fiber. At the front end, end users access the network through the wireless mesh that has stationary gateways. The user traffic travels over multi-hop through the gateway and reaches ONUs. WOBAN's popularity lies in that it can achieve cost-effectiveness due to the wireless access while having high capacity because of the optical backhaul.

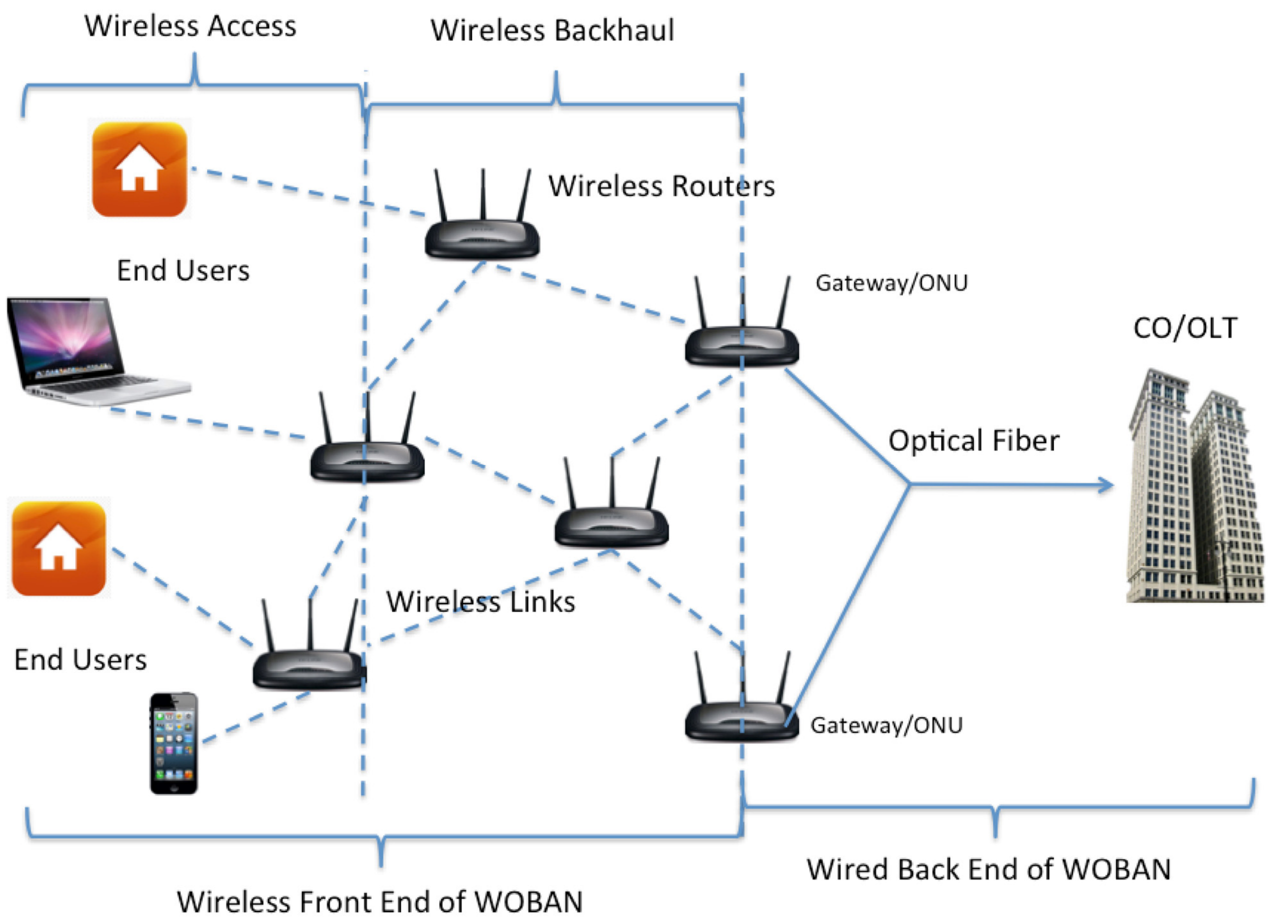

Figure 1. WOBAN Architecture.

There are multiple research efforts aimed at improving WOBAN such as management system and energy efficiency. Therefore the WOBAN architecture serves as a base for later discussion from the above aspects. Other researchers refer to WOBAN as FiWi BAN (Fiber Wireless Broadband Access Networks). To maintain the consistency between this survey and the references, we use the same terminology as the source. Therefore the term FiWi BAN may appear when discussing relevant works.

General BWA networks design involves several topics. The fundamental one, firstly, is to improve the capacity of the access network. Various works have been proposed including optimal relay station placement, bandwidth allocation scheme and direct communication mode between subscriber stations. Other relevant works focus on management systems for large-scale BWA networks and the performance comparison of multiplex techniques for 4G.

Another crucial concern when considering deploying BWA networks is energy and cost efficiency. Reducing the energy consumption not only saves electric billing but also helps to reduce carbon dioxide emission and is environment-friendly. Lots of research efforts have been put into this issue such as the study of energy efficiency from an architectural level, a mixed capacity access proposal, the study for reducing energy in long reach access and a green WOBAN design. Other important topics on BWA include the enhancement to survivability and specific application scenarios that can benefit from BWA networks.

The rest of the paper is organized as follows. Section 2 covers the enhancements proposed to improve the capacity, utilization and management of BWA networks. Section 3 is dedicated to a specific topic concerning the energy and cost efficiency of future deployments of BWA networks. A few application scenarios are discussed in section 4 and finally section 5 concludes this paper.

2. Enhancements Proposals

There are ongoing research efforts dedicated to improve BWA networks from various aspects. These topics includes the management system for large-scale networks, the optimal relay station placement scheme aimed at improving the network capacity and bandwidth utilization, the bidirectional bandwidth allocation approach for TCP in BWA networks, the adaptive direct communication mode between base stations and subscriber stations and the performance comparison between multiplex techniques. These research efforts are discussed in the following subsections respectively.

2.1 Management for Large Scale BWA

Expanding the coverage of the Internet to the next billion people would naturally lead to BWA networks of very large scale. Given the wide range of parameters and environmental phenomena that affect network operation, like many general wireless networks, BWA networks are inherently difficult and complex to manage. BWA networks are also be quite diverse, so network management platforms should be flexible to suit varying deployment requirements. To manage large-scale BWA networks, dedicated management approach maybe infeasible due to the huge additional cost and deployment overhead required. Therefore, simplifying network management is crucial to BWA. It is also a key requirement to simplify the specification of management goals for an effective distributed management system.

[Bernardi10] proposes the Stix platform to manage large-scale BWA networks. The management of BWA networks includes a wide range of activities such as fault, configuration, accounting, performance and security. Stix focuses on performance, fault and configuration management. It eases the management of community and ISP deployments while keeping the infrastructure scalable and flexible. Based on the notions of goal-oriented and in-network management, Stix allows administrators to graphically specify network management activities as workflows. Administrators are deployed at a distributed set of agents within the network that cooperate in executing those workflows and logging management information.

Figure 2 shows the architecture of a Stix agent. The communication manager is connected to other Stix agents. It is responsible for listening on incoming messages and forwarding them as workflows to the correct internal part. A workflow manager receives new workflows from the communication manager and determines the relevancy to local devices under management. If so, it stores the workflow, transforms them into proper forms and pass them down to the workflow engine. The workflow engine registers and schedules the workflow execution. The log overlay records local or neighboring log messages. The storage manager provides interfaces for appropriate database persistent storage. The device manager communicates with locally managed devices.

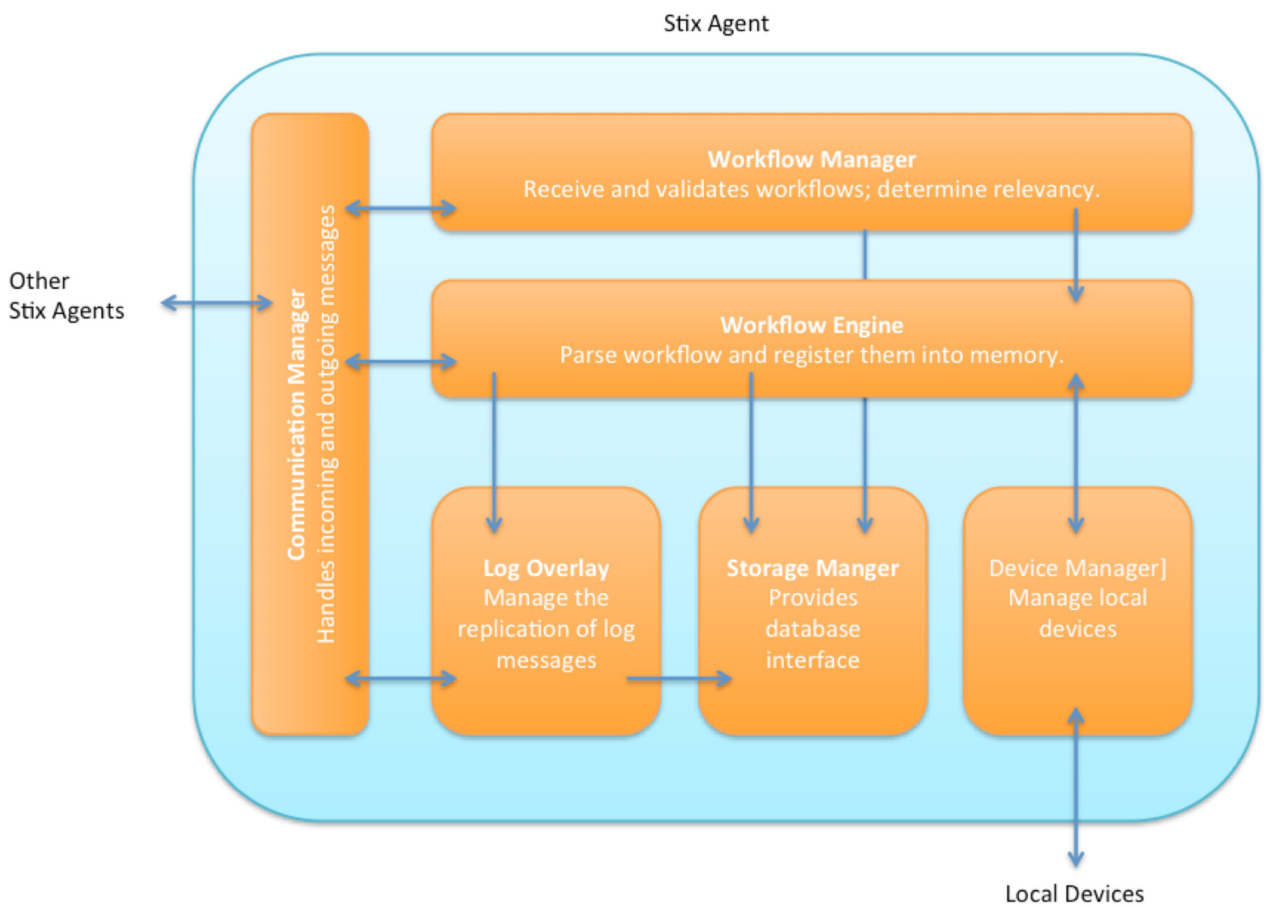

Figure 2. Stix Agent Architecture. [Bernardi10]

Stix is implemented on embedded boards and has a low memory footprint. The implementation generates operating topology and traffic data, showing that Stix can reduce the management traffic significantly, in comparison to common centralized management approach. Case studies are also used to demonstrate the ease of deploying the Stix platform for network reconfiguration and performance management. The author therefore point out the potential of Stix to be self-managing.

2.2 Relay Station Placement

Bandwidth and channel interference limit the kind of approaches that aim at maximizing resource utilization. Alternatively, cooperative relaying has been seen as one of the effective solutions to satisfy the stringent requirement of capacity enhancement for BWA. Deploying Relay Stations (RSs) can improve the quality of wireless channel for two reasons. First, the one long distance low rate link is replaced with multiple short distance high rate links. Second, obstacles between Base Station (BS) and Subscriber Station (SS) that affect channel quality can be effectively circumvented using RSs. As a result, placing RSs can deal with the legacy problems existing in current wireless network.

[Lin10] studied the RS placement problem and developed an optimization framework to maximize the capacity as well as to meet the minimal traffic demand by each SS. First, a new RS location planning design paradigm is presented. It incorporates the cooperative relaying into the network design. Second, to solve problem of the RS placement for maximum capacity, the authors develop an optimization framework. In comparison to traditional approaches that decouple the RS placement and bandwidth allocation into two separate phases, this framework jointly considers these two phases and output the optimal location placements along with the allocated bandwidth. The authors formulate such problem into MILP and seek solution through CPLEX. In addition, a heuristic algorithm is proposed to avoid the exponential solving time for the problem and produce the solution in polynomial time. Such timely solution can cope with growing traffic responsively.

A series of case studies and the numeric results from the simulation lead to two conclusions. First, cooperative relaying outperforms non-cooperative relaying in capacity given the same number of RSs. Second, the proposed heuristic algorithm solves the MILP problem much faster than the standard CPLEX with only a slight degradation in capacity performance. The cooperative relay placement strategy combining the heuristic algorithm provides an important guideline for future BWA network deployment and capacity planning.

2.3 Bandwidth Allocation for TCP

In IEEE 802.16 networks, ACKs are transmitted uplink over a unidirectional connection that is different from the downlink TCP flow. This behavior increases the round trip delay of the TCP flows because additional bandwidth has to be allocated for this ACK connection. The throughput also suffers accordingly. Regarding such behavior, a bidirectional bandwidth-allocation mechanism is proposed in [Park10] that couples the uplink and the downlink bandwidth allocation and thus increases the throughput of the downlink TCP flow and enhances the efficiency of uplink bandwidth allocation for the TCP ACK.

Firstly, an analytical model is presented to investigate the impact of the uplink bandwidth allocation delay on the downlink TCP performance. The simulation studies show that the piggyback method is not always available due to the burstiness of TCP. The authors conduct further studies to investigate the conditions under which the piggyback method will be available. Results show that when the bandwidth request delay is removed or reduced, the TCP throughput will be increased by up to 30% due to the availability of the piggyback mechanism.

After confirming the degrading effect, the authors propose the bidirectional bandwidth allocation scheme to address such impact. The scheme combines proactive bandwidth allocation with piggyback request to mitigate the drawbacks due to the proactive allocation. Figure 3 shows how the allocation scheme works. When serving a Downlink (DL) frame, the BS scheduler checks the Uplink (UL) queue to see if it is empty. If so, the scheduler enqueues a new bandwidth request for the SS. This is the proactive allocation approach. On the other hand, upon a UL frame, the scheduler checks if the packets are still in the DL data queue. If the queue is not empty, then the SS will request for bandwidth in a piggyback manner. In this way, the combined approach improves the UL bandwidth efficiency by using piggyback reactively while decreasing bandwidth request delay by using proactive allocation.

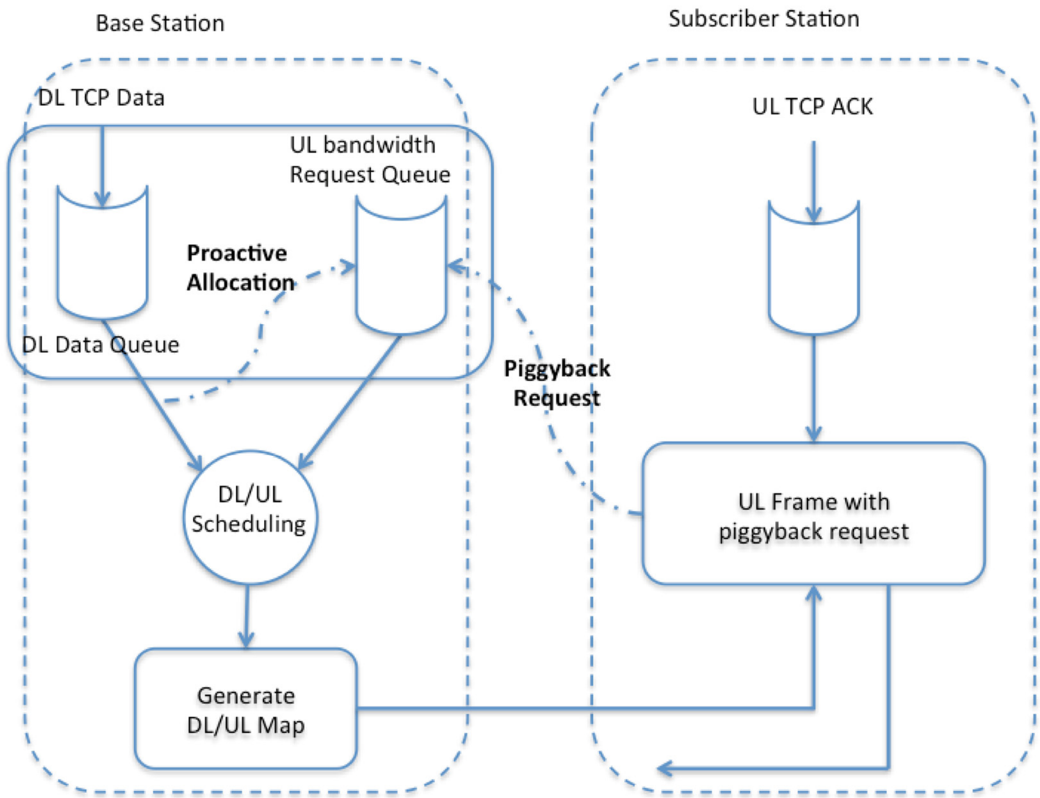

Figure 3. Schematic Diagram of the bidirectional bandwidth allocation. [Park10]

The combined scheme reduces the unnecessary bandwidth request delay and the signaling overhead because the needed bandwidth under such scheme is proactively allocated. According to simulation results, such allocation scheme can improve TCP throughput up to 40%. Moreover, the scheme is simple and easy to implement in the base station without causing modifications to the subscriber station or change to cross-layer signaling mechanisms.

2.4 Adaptive P2P approach for Subscriber Station

In IEEE 802.16 networks, the Point-to-Multipoint (PMP) mode is a well-adopted transmission type. In PMP mode, the Base Station (BS) serves as the centralized coordinator controlling and forwarding packets for the Subscriber Stations (SS). However, when two SSs intend to exchange packets, the BS is still required to reroute the packets. Obviously the communication bandwidth is wasted because of the rerouting. To address this problem, [Hsien11] proposes the Adaptive Point-to-point Communication (APC) approach to achieve direct communication between SSs within the PMP mode in IEEE 802.16 networks. Although under their proposal, the BS is still needed to coordinate and arrange time intervals for the SSs to transmit, the bandwidth consuming packets rerouting part is avoided. Given the additional APC mode, the channels can be utilized more adaptively by switching between the PMP and the APC mode.

Figure 4 depicts the switching process for packets transmission in APC. The switching between APC and the conventional indirect communication mode is dominated by certain constraint. Such constraint is calculated based on the channel quality between BS and SSs. Therefore, the APC mode always chooses the most efficient transmission for intra-cell traffic. As a result, the network throughput is expected to be increased using APC.

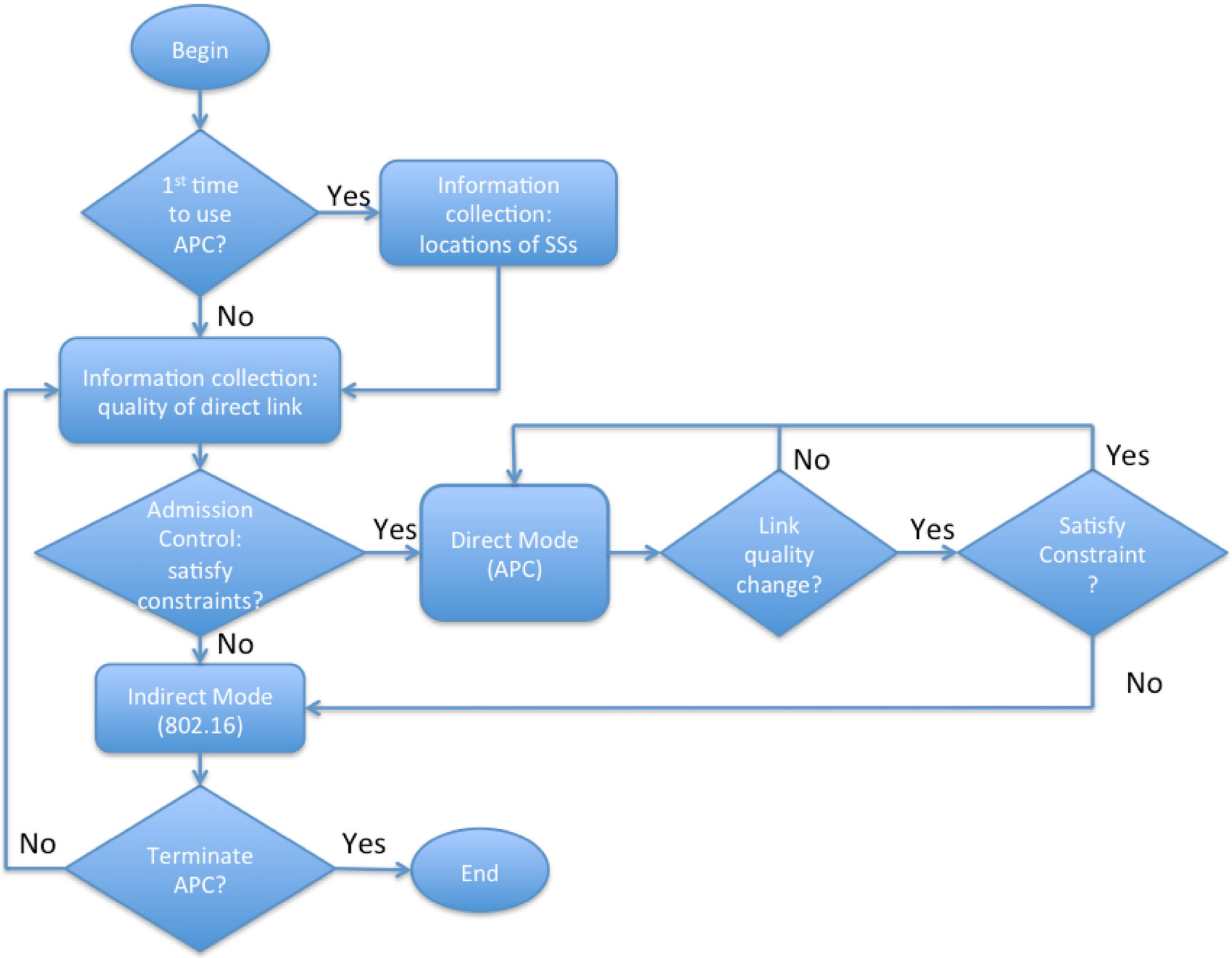

Figure 4. Flowchart of the switch of transmission mode. [Hsien11]

To confirm such expectation in performance improvement, the author first conduct theoretical calculations to derive the maximum number of MAC SDUs that can be transmitted and received within a frame. Then simulations are performed to validate such numeric model. In order to show the improvement after adding the APC mode, the performance analysis is conducted in a comparative manner. Conventional IEEE 802.16 and the proposed APC mode are compared in terms of saturation throughput in aspects of modulation mode, MAC SDU size and intra-cell traffic flow. The evaluation results show that by adding the APC mode, there is a significant increase in network throughput with the slight increase in network traffic overhead due to the additional coordination needed in BS.

2.5 Performance Comparison for 4G

The three most feasible multiple access techniques proposed for the fourth generation wireless communication systems (4G) are Orthogonal Frequency and Code Division Multiplexing (OFCDM), Orthogonal Frequency Division Multiplexing (OFDM), and Multi-Carrier Code Division Multiple Access (MC-CDMA). [Syed11] compares techniques in order to find the most suitable one for 4G implementation.

The transmitter structure of OFDM, MC-CDMA, OCFDM are shown in figure 5. In figure 5(a), in OFDM, the user data are viewed as a serial stream of bits and are modulated and converted into parallel sub-streams of bits. Each sub-stream is up-converted orthogonal to each other using the IDFT algorithm. At the end, cyclic prefix is added before the OFDM symbols are generated. Similarly, in figure 5(b) the MC-CDMA mode, before going into the OFDM processes, the parallel sub-streams are first spread across the frequency domain by a certain spreading factor. If before this, the user bits are also spread across the time domain as shown in the dashed square, the process becomes OCFDM.

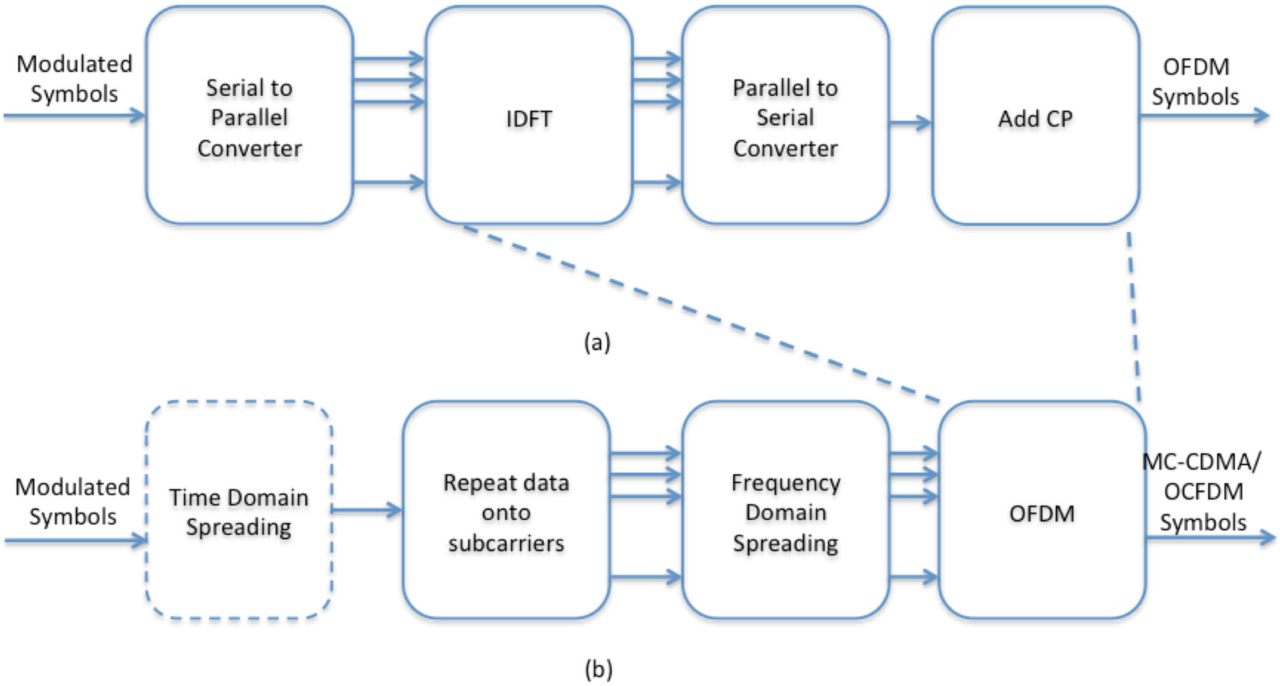

Figure 5. Block diagram of (a) OFDM transmitter; (b) MC-CDMA (solid line), OFCDM (dashed and solid line) transmitter. [Syed11]

To compare the performance, the modems of OFDM, MC-CDMA and OFCDM have been redesigned for fair comparison. The metric used for performance analysis is the probability of error in aspects of zero forcing and minimum mean square error. The results reveal that OFCDM provides the lowest bit error rate for a given signal noise ratio. Therefore it is considered most suitable for 4G.

3. Energy and Cost Efficiency

The access networks alone contribute a significant portion of the overall Internet energy consumption. With the increase of capacity demands in access networks, future-proof deployments should meet more stringent energy efficiency requirement. Traditional approaches lack energy efficiency because of their design paradigm that assumes the shortage of spectrum and the necessity of complex base stations. Therefore future approaches must be designed in an architectural level to provide inherent energy saving mechanisms.

3.1 Argument for Architectural Approaches

0.5% of the global energy consumption comes from mobile communication networks alone nowadays. Such energy consumption will be further increased in order to meet the growing demand for more capacity in BWA. The cost will increase from both deploying denser network infrastructure and the energy they will cost. Current cellular network technologies such as 3G and 4G are based on traditional design paradigms assuming spectrum shortage and the high cost of base stations. For example, 4G features high spectrum efficiency but low energy efficiency. Therefore network deployments prefer strategies with a few high-power bases stations of complex antenna systems. The blast signals through walls method used for indoor coverage is notoriously lack of energy-efficiency and is also not a sound idea considering radiation.

In the future, network deployment has to land on the tradeoff point among the cost of infrastructure, spectrum and energy. Despite the energy reduction made possible by improvements in electronics and signal processing technology, it is still not enough to match the energy consumption increasing in orders-of-magnitude because of the increasing demand in network capacity. Therefore, instead of solely increasing the efficiency of individual components, architectural solutions must be proposed in a broader scope.

[Tombaz11] proposes a framework to analyze the total cost of network development and research some recent architectural level "clean slate" proposals that radically take advantage of newly available spectrum, energy-efficient PHY layer designs and novel backhauling strategies aiming at minimizing overall system cost. They argue that network deployment should be tightly tailored to traffic requirements by utilizing more low-power micro base stations instead of the few high power high cost base stations. Taking backhaul into consideration, a power consumption model is presented and main tradeoffs among energy, base station and spectrum cost analyzed.

Using the power consumption model, decisions can be made based on the analysis of the main characteristics of the future network infrastructure and the cost of various components it contains. The authors then draw the following conclusions from their analysis. First, not only the energy cost but also the total cost of the access network heavily depends on the number of base stations. Whereas the high cost in energy of complex base stations is inevitable, the total cost can be minimized by deploy dense micro base stations. Second, the idle power consumption and backhaul become the major factor in total cost when deploying dense base stations. Third, the energy cost also heavily depends on the availability of the spectrum. When more spectrums are made available, both the energy and the infrastructure cost can be reduced significantly by using less complex base stations.

3.2 Mixed Capacity Access

Given the fact that the optical part of WOBAN has high capacity, the capacity of the wireless access part needs to be enhanced accordingly in a low-cost fashion. Deploying multiple transceivers at each side would certainly help improve the performance. However, this will also increase the equipment and energy cost leading to low cost efficiency. Instead, if we only increase the number of transceivers at those few nodes that often experience traffic overload, the goal of increasing the capacity can be achieved without a huge increase in cost.

[Reaz11] proposes the Mixed-Capacity Wireless Access (MCWA) architecture for WOBAN. Under MCWA, the authors study the problem of optimally introducing a limited amount of transceivers to the wireless nodes to improve the capacity of the access network without introducing heavy cost. They model such problem as a Mixed Integer Linear Program (MILP) and later solve it using CPLEX.

An efficient channel and radio assignment can improve the utilization of MCWA by reducing interference and contention in the wireless front-end of WOBAN. [Reaz11] also proposes one such scheme named Intelligent Channel and Radio Assignment (ICRA) for MCWA. ICRA balances the load among different channels to reduce interference as well as contention. This also can be formulated as a MILP and again solved using CPLEX.

3.3 Long Reach Access

[Shi13] focuses on the intersection between energy conserving and long-reach extension technologies in BWA networks. Several architecture level approaches are reviewed on saving energy in the context of achieving long reachability. These approaches shut down idle network elements such as transceivers, shedding the rate of transmission and adaptive configuration based on current traffic. These method covers the network on the ONU side, the OLT side as well as the wireless extension side.

The researchers implement their energy saving approach in two stages: the network planning stage and the traffic engineering stage. In the first stage, the problem is static and an energy-efficient network planning scheme is proposed incorporating an user assignment algorithm that is behavior-aware. Under such scheme, users that have complementary traffic behaviors are assigned to the same network to achieve continuous high bandwidth utilization. Accordingly, the number of needed bandwidth and transceivers are reduced, saving a considerable amount of energy.

In the second stage, the problem is about network operations that engineer traffic dynamically. The authors propose a Dynamic Wavelength Allocation (DWA) scheme to solve the problem. As shown in figure 6, different wavelengths are assigned to Remote Nodes (RNs) and changed dynamically based the current network traffic. In comparison to the fixed wavelength assignment method that pre-allocates the wavelength at aforementioned network planning stage, the DWA method utilizes the available bandwidth more efficiently in a statistically multiplexed fashion.

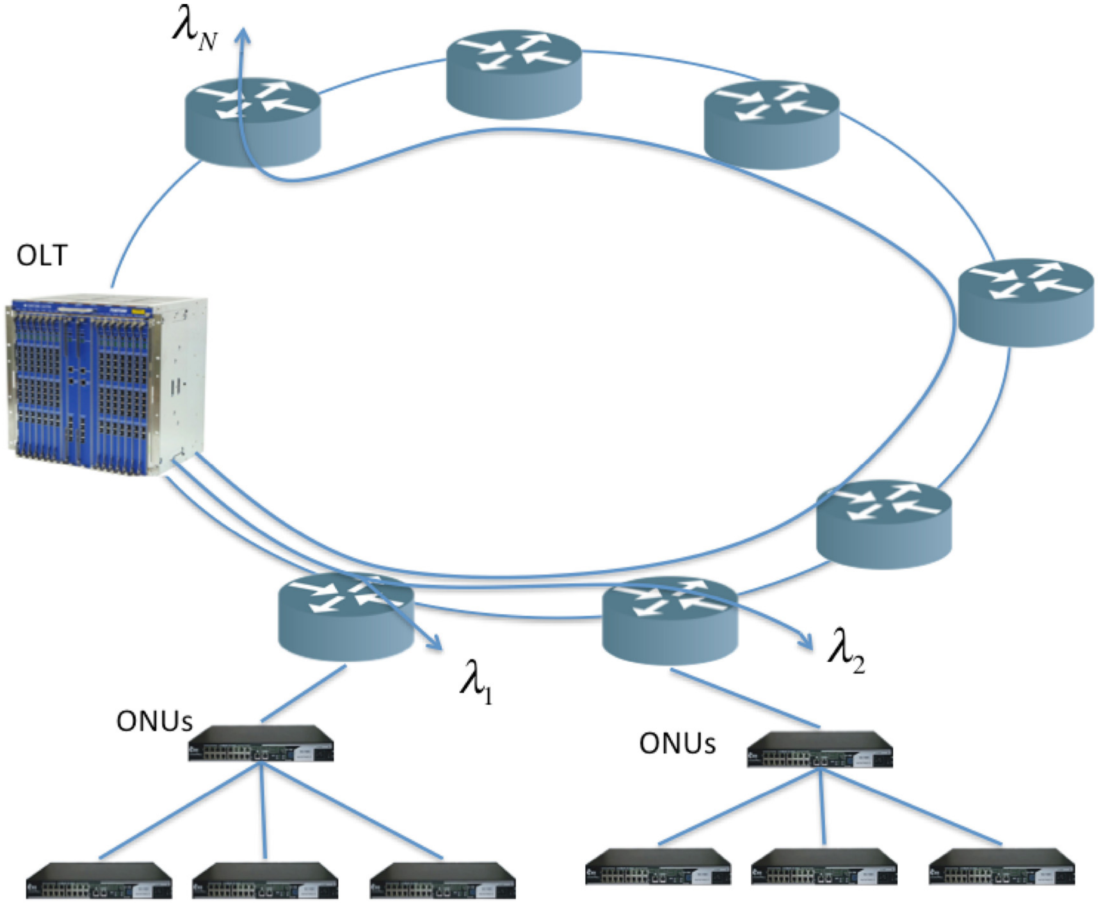

Figure 6. Adaptive Wavelength Allocation. [Shi13]

The authors therefore argue that extensive research attention should be paid to the study of network traffic patterns in order to support the approaches that reconfigure the network adaptively. Other energy saving approaches differentiating services according to both SLA and network utilization also provide a fair compromise between energy cost and network performance. These approaches should be included as a basic component in designing the next generation of long reach BWA networks.

3.4 Green WOBAN

From previous sections we can see that the WOBAN proposal has drawn a reasonable amount of attention. Among those research efforts, [Chowdhury10] dedicates its work on designing a very high-throughput and yet Green WOBAN. Novel energy saving techniques is employed to improve network utilization and energy efficiency.

As discussed before, there is an inherent capacity mismatch between the wireless front end and the optical back end of WOBAN. On one hand, the redundant capacity of the optical backhaul provides reliability guarantee in case of failure. On the other hand, such redundancy also leads to under-utilization during low-traffic hours. Regarding this discrepancy, the authors propose a coordinated ONU shut down algorithm that selectively put ONUs to sleep based on the low watermark and the high watermark threshold of the traffic profile. Thanks to the multipath feature of wireless mesh front end, user traffic can be rerouted to the active ONUs during the selective shut down.

Based on the shut down algorithm, the authors then develop a mathematical model to formulate the ONU selection problem. The model takes pre-assigned link capacities as inputs and generate a minimal set of ONUs needed to be active as output. Network parameters such as WOBAN topology and traffic are converted into constraints that can be used as guidelines for the ONU selection. With such model, a routing scheme is needed to reroute the traffic that originally take the path where the ONU is now put to sleep. In comparison to a load balancing routing scheme, the proposed routing aims at reducing network-wide energy consumption and is designed in a link state fashion. Residual capacity is assigned to a link as weight because it reflects the utilization of a link and thus indicates energy cost.

The authors use the MILP model as a benchmark to evaluate selection algorithm and the routing scheme. The impact of such energy aware design on the performance of WOBAN is analyzed over dynamic traffic profiles. The results show that appropriate configuration of design parameters can lead to considerable energy saving without significantly lowering the network performance.

4. Applications

Besides providing general access to the Internet, BWA can also be applied to specific scenarios that require high data rate or low latency. Such scenarios include both entertainment and emergency coping. A video streaming scheme for IPTV is discussed in 4.1. Then BWA deployments dedicated for emergency awareness is presented in 4.2

4.1 Video Streaming for IPTV

The video streaming services to end users are becoming more and more popular today. One of the successful examples is BBC's iPlayer. It allows viewers to stream their favorite TV programs on demand no matter the program is live or broadcasted in the past. The current technology behind iPlayer is Adobe Flash Player, partly as a result of the limitations of TCP that does not provide guarantee on delay nor bit rate. Therefore it is likely that TCP will be abandoned in the future when BWA is available to support IPTV.

Today's typical IPTV configurations contain a wireless access network from the TV to the gateway and a wired access to the metro network. Figure 7 shows a typical IPTV network topology where SS is for Subscriber Station and BS for Base Station. Node C is the source or destination of the video stream. Except for the bottleneck link of 5 Mbps rate, all the other links are of 100 Mbps.

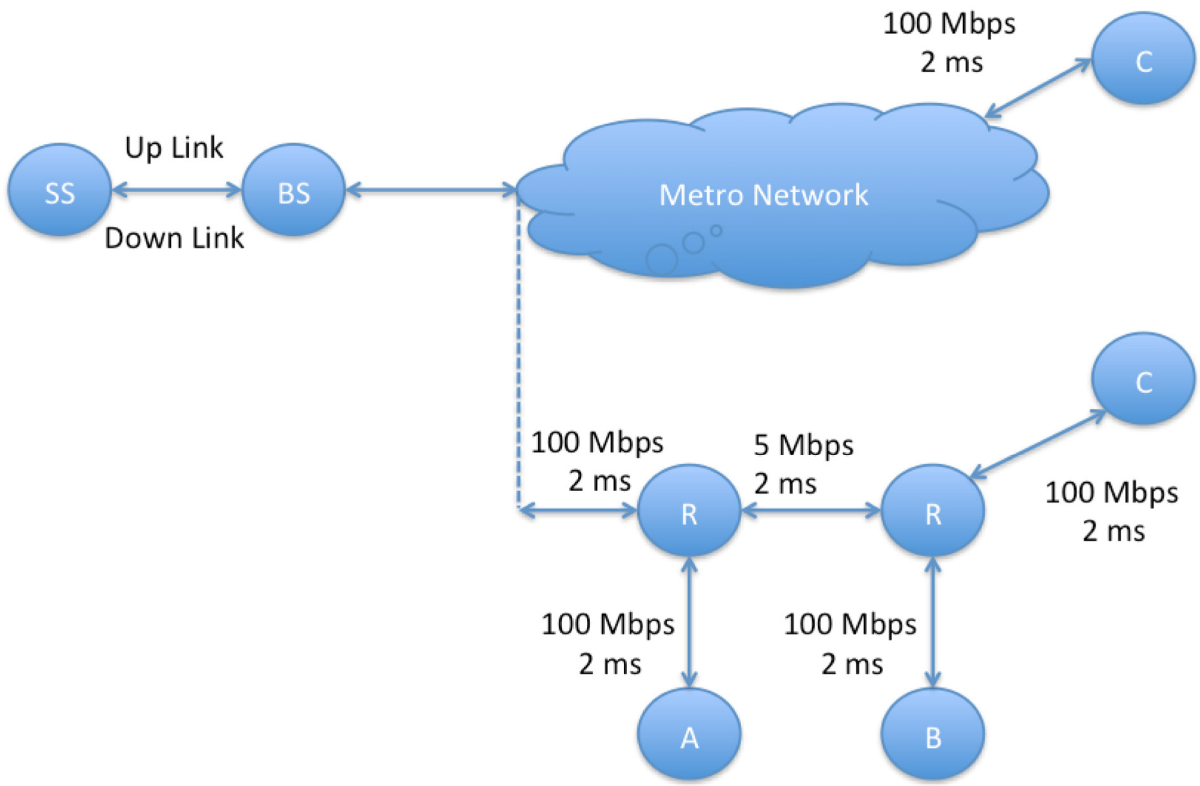

Figure 7. A typical IPTV network topology. [Al-Majeed10]

[Al-Majeed10] proposes the Broadband Video Streaming (BVS) scheme that employs a single Negative Acknowledged (NACK) for retransmission. The scheme is designed to reduce the packet loss without introducing significant delay. The BVS scheme is suitable for networks of short round-trip time, which is a feature shared by the IPTV network.

Table 1: Simulation Setting For BVS. [Al-Majeed10]

Parameter	Value
PHY	OFDMA
Frame Length	20 ms
Max Pkt Length	1 KB
Raw Data Rate	10.67 Mbps
IFFT Size	1024
Modulation	16 QAM 1/2
Guarded Band Ratio	1/8
DL/UL Ratio	3:1
Path Loss Model	Two-way Round

Two-way Round	Gilbert-Elliott
MS Tx Power	250 mW
BS Tx Power	20 W
Approx. Range to MS	0.7 kmt
MC	Mission Critical
Antenna Type	Omni-directional
Antenna Gain	0 dB
MS Antenna Height	1.5 m
BS Antenna Height	32 m

Using the simulation settings described in Table 1, the authors compare the BVS scheme with the industrial-standard Datagram Congestion Control Protocol (DCCP). DCCP uses TCP-Friendly Rate Control (TFRC) for connections handling. In single connection mode, TFRC misrecognized packet loss as congestion and thus reduce its sending rate. This lowers the utilization and lengthens streaming periods, which can be avoided by splitting a stream into several connections. The BVS scheme employs this option and allows the aggregate rate of the stream to compensate for individual connections. Therefore BVS achieves better utilization of the wireless channel and lower packets loss than DCCP.

4.2 Emergency Awareness Networks

Mission Critical (MC) systems such firefighting, police and healthcare, rely heavily on the underlying communication infrastructure to conduct tactical and emergency operations. Technological advancements in recent years are expected to help MC systems migrate from single data service to multimedia services. However, public networks are preceding the MC sector in both technology evolution and commercial deployment. So far the usage of the emerging FiWi BAN has been restricted to public users only. Mission-critical services for public safety and disaster responding communication can also benefit from such fiber-wireless integration.

To design an emergency awareness network using FiWi technology, key challenges such as fault recovery, QoS guarantee and security must be met. [Dhaini11b] proposes Mission Critical FiWi BAN (MC-FiWi BAN), the emergency aware network architecture that leverages layer-2 VPN to support mission critical services utilizing the FiWi integration. MC-FiWi BAN helps to extend the emerging BWA network to support MC services in rural areas. MC-FiWi BAN enforces MC service requirements such as high security, customize network control and critical messages with low latency by employing well-established VPNs. Each VPN responds to a specific type of mission-critical service that requires the bundle of Service Level Agreement and effective resource management paradigm.

The building blocks of MC-FiWi BAN include layer-2 VPNs over BWA networks, VPN tunneling in intra- and inter- domains, the support for fault tolerance and error recovery and the QoS support for emergency awareness. Other design issues such as service classification, VPN resource management, QoS provisioning for VPN are also discussed. Due to the scale of the design problem, the authors only use an illustrative simulation example to generate results for validation purposes. It is clear that more works need to be done before a concrete implementation of MC-FiWi BAN can be achieved. Nonetheless, the proposal for MC-FiWi BAN is novel and with foresight. As BWA networks continues to gain popularity, it can be envisioned that MC networks such as MC-FiWi BAN can eventually become practice.

5. Summary

This survey first presents results from several proposals that provides enhancement to the BWA network. The key feature of the Stix system is the distributed and in-network management approach. The optimal RSs placement can be achieved by combining the location placement and bandwidth allocation period. The bidirectional allocation scheme improves TCP throughput by switching between the proactive bandwidth allocation and the reactive piggyback approach. An APC mode is proposed into the PMP mode IEEE 802.16 network in order to provide direct communication between SSs and improves the channel utilization by reducing the bandwidth wasted on rerouting through BS. The comparison of multiplex techniques concludes that the OCFDM is most suitable for 4G networks.

Energy and cost efficiency is a big issue concerning BWA deployment. There is increasing works arguing for energy efficiency at an architectural level because of the large scale and capacity of future BWA networks. Specifically, the mixed capacity approach improves the utilization of the network by adding transceivers only to those stations that have intensive traffic. The proposal for long reach access networks assigns users of complementary traffic behavior and dynamic assigns bandwidth to remote nodes. The green WOBAN proposal aims at selectively putting ONUs to sleep to reduce the energy wasted due to low utilization during low traffic hours.

Finally, two application scenarios leveraging BWA are presented. The BVS scheme for IPTV uses a single NACK mechanism that reduces uplink bandwidth request and improves the total data rate of video streaming in comparison to standard approach. MC-FiWi BAN is proposed to extend BWA services to mission critical sectors by leverage layer-2 VPN services.

6. List of Acronyms

The acronyms are listed alphabetically.

Acronym	Standing For
4G	the 4th Generation wireless communication systems
APC	Adaptive Point-to-point Communication
BS	Base Station
BVS	Broadband Video Streaming
BWA	Broadband Wireless Access
DCCP	Datagram Congestion Control Protocol
Fi-Wi	Fiber-Wireless
ILP	Integer Linear Program
ICRA	Intelligent Channel and Radio Assignment
IPTV	Internet Protocol Television
LR-BWA	Long Reach Broadband Wireless Access
MILP	Mixed Integer Linear Program
MPMC	Maximum Protection with Minimum Cost
MC	Mission Critical
MC-CDMA	Multi-Carrier Code Division Multiple Access
MCMF	Minimum Cost Maximum Flow
MCWA	Mixed-Capacity Wireless Access
NACK	Negative Acknowledgment
OBOF	Optimizing Backup ONUs selection and backup Fibers
OFCDM	Orthogonal Frequency and Code Division Multiplexing
OFDM	Orthogonal Frequency Division Multiplexing
ONU	Optical Network Unit
P2P	Point-to-Point
PMP	Point-to-Multipoint
PON	Passive Optical Network
RS	Relay Station
SS	Subscriber Station
TFRC	TCP-Friendly Rate Control
VPN	Virtual Private Network
WOBAN	Wireless Optical Broadband Access Networks

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Last Modified: April 30, 2014

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