Wireless Broadband: Comparative Analysis of HSDPA vs. WiMAX

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Abstract—The ever growing demand for data and multimedia content has seen a surge in evolutionary wireless networking. This growth, largely driven by the success of data and media streaming over the all-encompassing communication medium, the internet, and ubiquitous availability of digital multimedia technology, has seen a sudden influx of partly complementary, partly substitutive network technologies such as HSPA, WLAN, WI-FI, Flash-OFDM, DVB-H and Bluetooth, bringing with them an upsurge in throughput (in Mbs). This paper gives an overview of the comparative analysis of two major technologies HSDPA and WiMAX, as a precursor to the complete experimental and simulation study of real-time streaming services (video) and optimization of existing networks. This paper will focus on technical comparisons with simulation examples, giving suggestions as to why the disparities in performance exist.

Index Terms—HSDPA, WiMAX, CDMA, OFDMA

I. INTRODUCTION

The demand for data especially streaming services over wireless networks has been largely influenced by the success of streaming applications in the internet domain. However, while the wired network can be reliably modeled for large throughputs, properties of the radio interface are time-varying making it difficult to replicate this success. It's given that the growth of data services have increased tremendously, but the bulk of this surge has been mostly to low-bandwidth applications such as SMS, downloads of ring tones, pictures and MMS. Movie downloads, emails, file down/uploads and real-time media streaming onto PDAs and Laptops have seen slow growth. This has been largely due to pricing, spotty coverage, low data rates, poor latency, user equipment that only partly or completely do not support these services and a general trend by operators to have a vindictive capital investment. Operators have therefore, continued to develop voice services since most of their revenue are made from voice networks.

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Since the bandwidth requirements and extensive use of data and multimedia applications were far overwhelming the capacity of existing technologies such as GPRS, EDGE and Ev-DO, in addition to the fact that most access technologies did not have the option to differentiate specific application demands or user needs, wireless technologies had to evolve to cope with this demand. This evolution in wireless networking brought an influx of technologies that are driven by among other things a revolutionary desire to reduce cost of back-haul traffic, achieving interconnectivity between different providers and equipment, enhancing security and QoS, reducing cost on the last mile access and above all achieving true mobility.

It's not surprising to see broadband wireless networks streaming live video broadcasts, distance education, corporate telecasts, etc. However, these technologies are dependent on standardization from different groups notably 3GPP/2 and 802.11/6 working groups, Wi-Fi Alliance and WiMAX forum which due to incohesion retards progress in wireless broadband.

Large swathes of geographical South Africa are without broadband coverage or coverage of any sort, even when they exhibit potential for consumption of such services. It's instructive to note that some of these areas are even in urban centres, resorts or along busy highways where such services are no longer luxuries but necessities. The need therefore, for a proper study of the system end-to-end behavior of traffic patterns of these applications in order to develop workload models as well as insights into network traffic engineering and capacity planning for such applications, can not be overstressed.

Competition between HSDPA and WiMAX is unavoidable, at least for now, if only for the simple reason that their current objectives cross-cut into each others traditional turf. HSDPA is moving into data technology, the springboard of WiMAX while WiMAX is reaching into voice technology, the evolutionary precursor of HSDPA. However, there is consensus amongst industry players that differences in performance indices will not influence the technology adopted rather providers will have to choose which fits with their requirements, when and where. This decision is likely to be made easier in the near future when the technologies finally converge towards OFDMA, IP Core and IMS.

This paper discusses the technical similarities and differences of key features followed by comparison indices such as coverage and capacity, mobility, network architecture, spectral analysis and associated techno-economics.

II. WIRELESS BROADBAND TECHNOLOGIES

A. HSDPA

HSDPA is a feature of UMTS Rel’5 that extends the features of 3G in the downlink with a theoretical peak throughput of 14Mbs[21]. It is a shared channel transmission, with a percentage (commonly 80%) of the total downlink radio resource shared dynamically by users fundamentally in time but also in the code domain. The code multiplexing is enabled to effectively support small payloads and UEs that may not de-spread the available 15 codes.

HSDPA introduces new features that enhance the 3G primary radio bearer Downlink Shared Channel (DSCH). These features include, a new transport channel High Speed - DSCH (HS-DSCH) that acts as the new primary radio bearer, Adaptive Modulation and Coding (AMC) for fast link adaptation, fast Node B scheduling to control allocation of channel rapidly, shorter Transmission Time Interval (TTI) to improve latency, fast PHY layer Hybrid-ARQ with soft combining for error control and multicode operations (fixed SF=16).

To achieve all these three features of WCDMA have been removed, namely, fast power control, soft handoff and Variable Spreading Factor (VSF), whereas the RNC remains unchanged to provide ciphering and backup during handoffs or some other failure by HARQ. The RNC-MAC is also equipped with a new functionality that handles flow control and backward compatibility with 2/3G. There is also a new MAC-hs at the Node B to handle scheduling, HARQ related functionality. These features are tightly coupled and permit a per-TTI adaptation of the transmission parameters to the instantaneous variations of the radio channel quality.

i. Shared Channels

HSDPA is a shared channel resource, where HS-DSCH is shared amongst users both in time and code dynamically by the scheduler based on per TTI radio conditions of the UE. The HS-DSCH is the primary radio bearer with a logical channel structure that can be viewed as a pool of physical channels (channelization codes, up to 15), the High Speed Physical Downlink Shared Channels (HS-PDSCH). These channels carry data to the UE from the Node B and maybe multiplexed in code by the scheduler to different UE depending on channel conditions or payload.

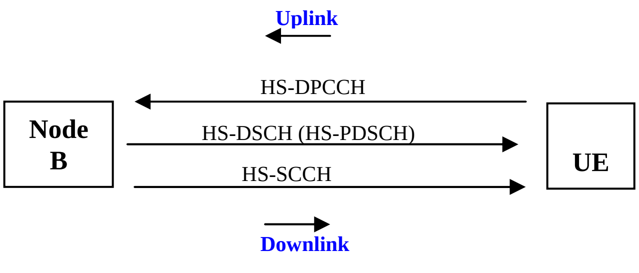

Fig. 1: Block Diagram of HSDPA Channels

The High Speed Shared Control Channel (HS-SCCH) is a physical signaling channel in the downlink used to set up HS-PDSCH HARQ. Lastly the High Speed Dedicated Physical Control Channel (HS-DPCCH) is a physical channel carrying feedback from the UE in the uplink such as ACK/NACK and Channel Quality Indicator (CQI) for ease of scheduling by the Node B as shown in fig. 1 [2][3][13].

ii. Fast Scheduling

Dynamic scheduling is perhaps the sole determinant of HSDPA performance in a capacity limited network. The Node B scheduler decides who receives what every TTI and together with the link adaptation mechanism, at what data rate. The scheduler utilizes multi-user diversity, defined as the gain achieved by transmitting to users with higher C/I, and the cell capacity maybe significantly enhanced by higher long-term unfairness while observing QoS requirements i.e; The scheduler may base decisions on predicted channel quality, the current cell loading or the traffic priority class (real-time or non-real-time services) or a combination of some or all the above. It may be implemented as Proportional Fair (PF), Round Robin (RR) or Maximum Carrier to Interference (CI).

Since the thoroughput at UE is a function of the scheduling scheme employed at Node-B, it becomes important to analyze it in detail. The total cell throughput of a HSDPA system having a total of N_u users with a mean bit rate of R_i is given by [11]

$$T = E\left(\sum_{i=1}^{N_u} R_i\right), \qquad (1)$$

where for RR, R_i is given by

$$R_i = \frac{1}{N_u}\sum_m k_m \frac{W}{SF}\frac{\left(N\log 2(M)\tau\right)_{m,i}}{N_{s,i}}, \quad (2)$$

iii. Hybrid ARQ

HARQ is used with soft combining i.e. if UE requests for a retransmission of Transmission Blocks (TB) received in error; it keeps the soft copy of the TB received in error and combines it with the subsequent retransmission to improve on the probability of successful decoding. HARQ always uses a Stop and Wait (SAW) mechanism. It further helps to fine tune effective code rates and compensates for the errors made by the link adaptation mechanism. It can be implemented either as chase combining, where the retransmitted TB is the exact copy of the first transmission or as Incremental Redundancy (IR), where the retransmission has parity bits not in the original TB.

iv. Fast Link Adaptation

In circuit switched systems (CS) the services as voice have mostly constant bit rates and therefore its necessary to implement fast closed loop power to maintain constant bit energy to Noise (Eb/N0) and combat fading. However in bursty data traffic that can tolerate jitter we can achieve the same objective of constant Eb/N0 by keeping the transmission power constant and adjusting the data rate. This adjustment is easily achieved by the scheduling mechanism and the modulation scheme. The scheduler shares the channel resource based on the channel conditions (which are independent) of individual UEs.

The channel coding rate is therefore adjusted and a suitable modulation scheme Quadrature Phase Shift Keying (QPSK) or 16-QAM (Quadrature Amplitude Modulation) chosen based on the channel conditions [Fig. 2]. The MAC-hs selects the MCS that match the instantaneous radio conditions which selection depends on the CQI, instantaneous power of the associated dedicated physical channel, QoS demands of the requested service and waiting buffer sizes.

Links with better channel conditions are assigned 16QAM and higher coding rates. This ensures higher throughput, low interference variation and high effectiveness in combination

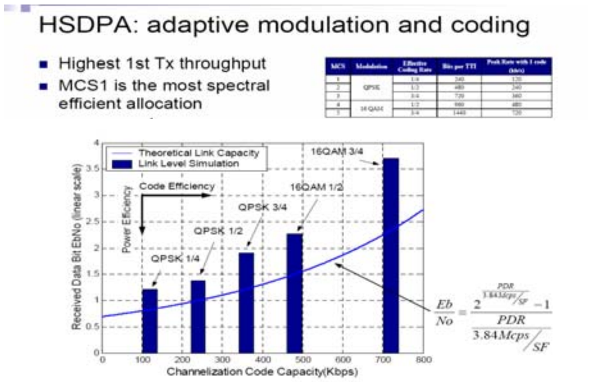

Fig. 2: Received Data Bit Energy to Noise Spectral (PDR) per Code. - Source: Nokia

with fat pipe scheduling.

B. WiMAX

Worldwide Interoperability for Microwave Access - WiMAX is a generic term used to describe wireless systems based on the WiMAX certification profiles derived from the IEEE 802.16–2004 Air Interface Standard (amended Dec 2005 to include subscriber station mobility, IEEE 802.16e).

WiMAX has been defined in two systems: the “Fixed WiMAX” often used to describe 802.16d based systems that feature OFDM/TDMA modulation and address the fixed wireless DSL market and “Mobile WiMAX” to describe 802.16e based systems, which feature S-OFDMA modulation and address both the mobile broadband and fixed wireless DSL markets.

WiMAX relies on an all–IP packet network architecture and advanced radio features (minimizing CAPEX), in this regard WiMAX 802.16e perhaps offers a better opportunity to address the needs of broadband with some degree of ‘mobility’ (actually portability).

WiMAX 806.16e operates in the licensed 2 to 6 GHz range. Mobile applications are likely to operate in frequencies below 3GHz with some minimal support for 802.16d applications. The most glaring anomaly with mobile WiMAX is that it does not support backward compatibility. Mobile WiMAX is designed with typical cell radii of 2 to 5km at theoretical peak throughputs of 30Mbs while operating on 10MHz channels. One major advantage of 802.16e over 802.16d is that it can operate over NLOS enhancing better connectivity.

i. *Multiple Access and Modulation Technologies*

1) OFDM: Broadband systems are highly sensitive to interference in the channel and multipath and therefore a good radio access technology is paramount in alleviating these problems. OFDM eradicates or in the very least minimizes the effects of most of the disadvantages encountered with multiplexing in wireless systems. It partitions the spectrum into many narrowband orthogonal sub-carriers and adds a cyclical prefix guard interval to make the signal robust to multipath delay spread, allowing a higher modulation scheme and hence higher data rates.

The sub-carriers use long-duration symbols in the time domain so that they are less like to suffer distortion due to multipath. The number of sub-carriers is a base two function of channel bandwidth and desired interference. Usually it corresponds to the FFT size, typically 256 in 802.16d and 512 to 1024 in 802.16e.

An OFDM signal is the sum of N independent modulated symbols mapped onto N different sub-channels with 1/T frequency separation, where T is the OFDM symbol period. The discrete time-domain samples bi = ($b_0^i, b_1^i, ..., b_{N-1}^i$) to be transmitted are obtained by performing an N-point IFFT on the complex QAM symbols block ai = ($a_0^i, a_1^i, ..., a_{N-1}^i$) [11]:

$$b_m^i = \frac{1}{\sqrt{N}} \sum_{m=0}^{N-1} a_m^i e^{j2\pi mn/N} \qquad (3)$$

where the QAM data symbol aim is sent on the m^{th} sub-carrier of the i^{th} OFDM symbol. The OFDM symbol index is omitted in the sequel.

2) OFDMA: this is a multicarrier technology that extends OFDM by assigning individual groups of sub-carriers to particular CPEs. Sub-carriers maybe scattered throughout the spectrum, Full sub-channelization –FUSC, clusters of sub-carriers forming sub-channels maybe scattered in the spectrum, Partial USC or sub-carriers composed of contiguous groups of sub-carriers, Adaptive Modulation and Coding -AMC maybe selected[6].

3) S-OFDMA: Scalable-OFDMA allows the adjustment of OFDMA with respect to the available channel bandwidth. This is helpful in ensuring that different regulatory spectral assignments result in the same symbol rate [6][17]. See Fig 3 (a & b) and Table 1 for summary of OFDMA parameters and spectrum.

TABLE 1: OFDMA PARAMETERS

Parameters	Values				
System BW (MHz)	1.25	2.5	5	10	20
Sampling Freq (Fs)	1.429	2.857	5.714	11.429	22.857
Sampling Time	700	350	175	88	44
FFT Size (N_{FFT})	128	256	512	1024	2048
Subcarrier Freq Sapcing	11.16071429kHz				
Useful Symbol Time (Tb)	89.6μs				
Guard Time (Tg=Tb/8)	11.2μs				
OFDMA Symbol Time	100.8μs				

ii. *Smart Antennas*

These refer to a class of antenna technologies designed to improve the received signal strength. They achieve this by improving the Carrier to Interference plus Noise Ratio CINR. Smart antennas employ techniques such as Multiple Input Multiple Output (MIMO) for diversity coding schemes, Space-Time Coding to implement transmission diversity, Beam Forming by transmitting from several antennas at specific relative phases to narrow beam width and improve link budgets and Deployment and frequency re-use.

III. Comparison of Key Metrics

As we stated earlier in the introduction these two technologies are trying to venture into what has been considered the evolutionary services of the ‘competition’. This section is going to present comparisons of key performance metrics giving simulation results (using MATLAB and NS2) of these metrics where applicable.

A. CDMA vs. OFDMA

The HS-DSCH has a fixed Spreading Factor of 16codes of which one is reserved for signaling. This means effectively that a user experiencing good CI or near the Node B and capable of dispreading the 15 HS-PDSCH available can use 16QAM. However, since all the users are time miltuplexed on the same spectrum, in spite of their geographical location, the combined effect of interference and multipath will most

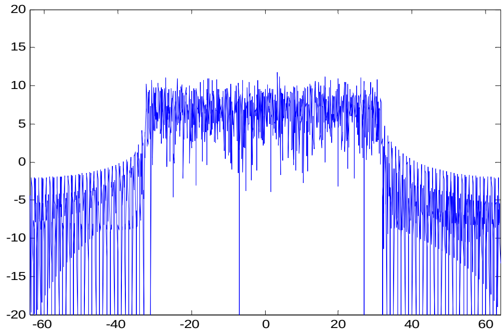

Fig. 3b: The Spectrum of FDD/OFDMA System

certainly result in the use of the lower coding scheme, QPSK.

OFDMA on the other hand can only select between 16 and

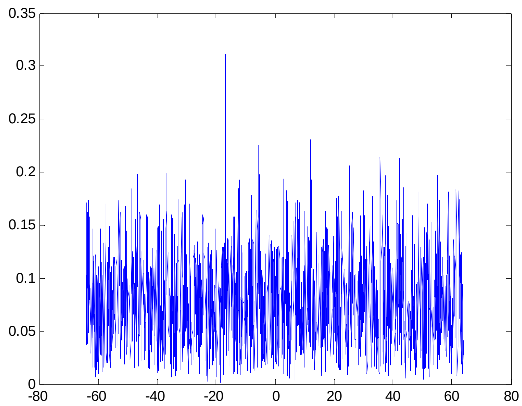

Fig. 3a: The Spectrum of TDD/OFDMA System

64QAM depending on channel conditions. It is therefore using a higher modulation scheme plus sub-channelization. In addition to this can utilize the technique of Space Division Multiple Access (SDMA); the CPE chooses only to concentrate transmit power on the channels that are experiencing good conditions or avoid channels that experience deep fades.

TDD/OFMA, on the other hand, has a dynamic channel distribution for the overall spectrum-efficient allocation, expanding the downlink or uplink bandwidth depending on which whose traffic is low [18].

B. Coverage and Capacity

In spread spectrum access technologies coverage and capacity are closely related. This can be viewed from the point of interference and multipath. When there is increased multipath to the radio signal such that fewer UE/CPEs are served then of course capacity is reduced.

Link budgets and path loss are instrumental in coverage calculations. Link budgets yield maximum path loss in a channel without degrading the transmitted data. Since

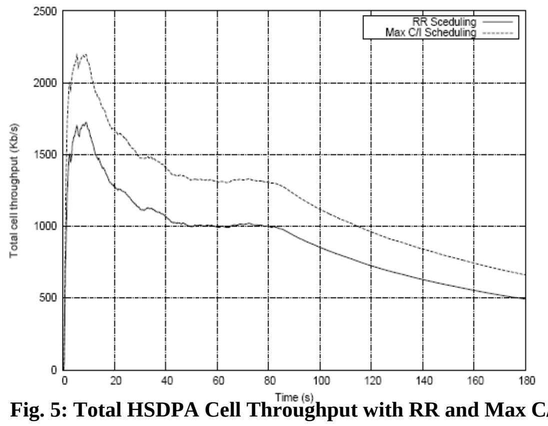

Fig. 5: Total HSDPA Cell Throughput with RR and Max C/I Scheduling

WiMAX will be using higher carrier frequencies the associated attenuation will be higher requiring as many cell sites for a given HSDPA cell[10][23].

Direct Sequence Spread Spectrum, DSSS [17] technologies such as CDMA are very susceptible to fading and shadowing and symbols received in excess of symbol duration cause Inter-Symbol Interference (ISI). Fig. 5 shows how different scheduling techniques can enhance or reduce throughput thus capacity and coverage calculations. OFDMA systems however suffer mostly from the Doppler shift such that the sub-carriers are no longer orthogonal resulting in Inter-Carrier Interference.

Capacity of a wireless network is usually a function of its bandwidth and spectral efficiency. HSDPA has Circuit Switched (voice telephony) systems inheritance and scalability of spectrum is not an inherent advantage of voice networks. However, WiMAX is an end-to-end all-IP systems designed for broadband wireless.

C. Network Architecture

The 802.16 standards only define the interface comprising the PHY and MAC layers, whereas 3GPP [1][2][3] defines the entire network architecture from the lower layers to higher level layers Fig. 6 illustrates this difference[23] [27].

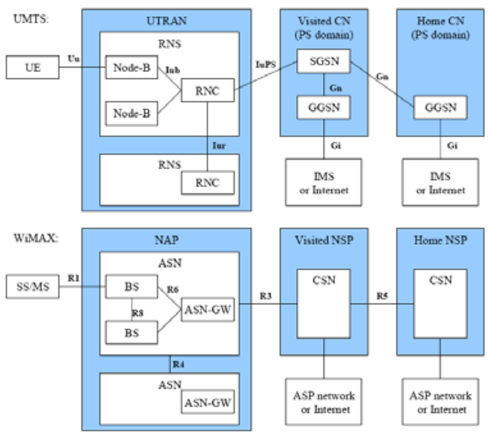

Fig. 6: Network Architecture for UMTS and WiMAX systems

D. *Mobility*

HSDPA as mentioned earlier has voice telephony inheritance, thus it has tremendous advantage over WiMAX in terms of mobility. This can be viewed in terms of handoffs [8]. Whereas HSDPA utilizes hard handoff WiMAX uses three; hard, fast base station switching, and macro-diversity handoff. The point of note here is the fact that handoffs are done when a UE/CPE are mobile. Since WiMAX has more cells for a given HSDPA cell, there is always a higher likelihood that the handoff will fail due to crossing over many cells within a short period of time. This makes WiMAX only very efficient in 'portable' or 'nomadic' situations.

E. *QoS Requirements*

HSDPA and Mobile WiMAX provide suits of tools to support QoS for multiple applications whether for real time, background, interactive or streaming services. The 802.16 standards however specify a more robust and secure QoS requirements.

F. *Antenna Technologies*

WiMAX and HSDPA have the options of implementing various antenna technologies to enhance capacity and coverage. However, these technologies are easily implemented in WiMAX than in HSDPA. Figs 7 and 8 illustrate how MIMO enhances the capacity of WiMAX systems. It's noteworthy that most CPEs do not support these upgrades in technology, so that their presence brings minimal advantage.

G. *CAPEX and OPEX*

HSDPA is implemented over existing 3G networks, sometimes with as little as just a software upgrade or as much as hardware cards (MODEMs) at the RNC and Node B. Unless a new 3G network is being rolled out, the Capital expenditure (CAPEX)[9] is very low. The Operational Expenditure is also in the tune of 20% less than in 3G networks. There are hardly any fully WiMAX commercially functional networks. This could be attributed to the fact that CAPEX for the same coverage as HSDPA is much higher, since the operators would have to start from scratch and with low demands the venture might not be commercially viable. A classical example is the South Korean provider Hanaro and

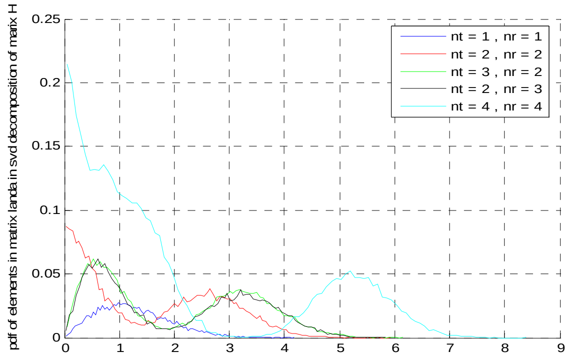

Fig. 7: PDF of a MIMO Matrix, for transceivers with 1 to 4 Antennas

its WiBRO network.

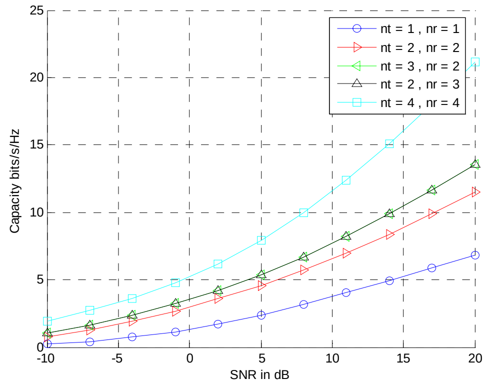

Fig. 8: Capacity of a MIMO Matrix, for TRx 1 to 4

IV. RELATED WORK

This paper as mentioned earlier is a precursor to 3 other papers in the on going research work on Video streaming over HSDPA and WiMAX, optimization of the 3G network to effectively handle real-time streaming services and the possible heterogeneous network solution to the streaming problem over wireless networks. Simulation and experiments are currently on-going on installed networks and results shall be released as soon as they are completed. It's important to note however, that modeling and simulating HSDPA and WiMAX represents a big challenge. HSDPA for having very few versatile event driven simulators as is the case in the WLAN/MANET scenarios and WiMAX for a very complicated standard [5], employing state-of-art wireless air interfaces and MAC protocols. The need therefore, to do a data-driven (signal) simulation and event-driven (protocol) simulation. This most of the time arises from lack of a comprehensive tool to evaluate the performance of both technologies as a unit system. NS2 is being used and where applicable MATLAB.

V. CONCLUSION

The provisioning of broadband services over wireless networks has significantly two things to address; Mobility and higher Throughput. In this regard then WiMAX and HSDPA seem to be on extreme ends of the problem. HSDPA can deliver full mobility plus the advantage of existing functional network, while WiMAX can guarantee higher data rates, but neither structure nor satisfactory mobility. The way forward is therefore a heterogeneous network where the mobility of HSDPA and the higher throughput of WiMAX are exploited to achieve a successful mobile wireless broadband.

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