HWN* Mobility Management Considering QoS, Optimisation and Cross Layer Issues

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***Abstract*—In this paper, we address mobility management for 4th generation heterogeneous networks from a quality of service (QoS), optimisation and cross layer design perspective. Users are classified as high profile, normal profile and low profile according to their differentiated service requirements. Congestion avoidance control and adaptive handover mechanisms are implemented for efficient cooperation within the mobile heterogeneous network environment consisting of a TDMA network, ad hoc network and relay nodes. A previous proposed routing algorithm is also revised to include mobility management.**

***Index Terms*—Handover, QoS, Routing, Mobility, HWN*.**

I. Introduction

THE two main mobile network topologies considered are the Base Station (BS) Oriented Mobile Network (BSON) and the 802.11 based Mobile Ad hoc Wireless Network (MANET). In a BSON Mobile Terminal (MT) communication is based on single hop communication with the Base Stations (BSs) while for a MANET, MTs communicate with one each other either directly through one hop or indirectly via multi-hop links. Our investigation shows that the BSON has a better performance than the MANET in terms of communications reliability, service delay, data rate, and throughput per unit etc, but the MANET has advantages in terms of low cost, self-configuring ability, and flexibility. However, routing is a challenge for a MANET as communications paths are transient due to node mobility. Any position changes made by MTs participating in an established route can make this route invalid.

We propose to combine the advantages of different networks so that the MTs can utilise an optimised MANET or the BSON and packet relay services. Figure 1 presents our Hybrid Wireless Network with Relay Nodes (HWN*) connected to an IP network. The relay nodes (RNs) compose a mesh like structure, while BSs are connected to an IP network via switches. Two MTs may communicate through an intermediate node. This node can be a MT, a fixed RN or a group of RN matrices. When a MT transmits packets to a BS through RNs, the RNs extend the signalling coverage of BSON thus we can expect an enhanced resource sharing performance. The primary goal of the RN incorporation in hybrid system is to provide uniform coverage. For example, A MT may borrow cellular data channels that are available thousands mile away via secure multi-hop RNs, where RNs are placed at flexible

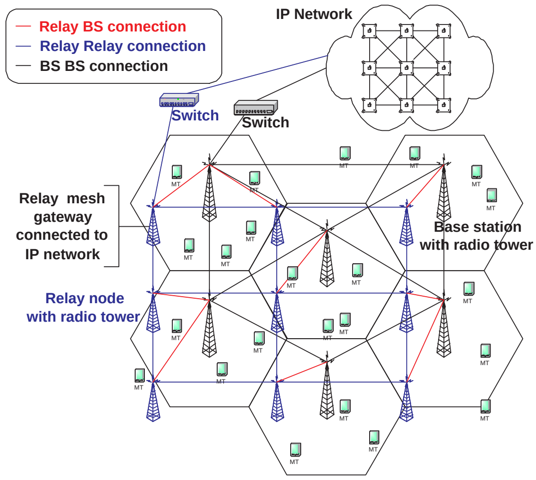

Fig. 1. The hybrid wireless network with fixed relay nodes (HWN*) and IP network

locations in the network. The MT can also communicate with each other or access internet ubiquitously. A further discussion on the HWN* topology description can be found in [2].

The HWN* can provide an application service with an associated cost to subscribers. The subscribers use MTs with multiple Radio Access Technology (RAT) capability that can send and receive multimedia traffic with different QoS expectations. It is envisaged that MTs should instantly access the most effective RAT with a seamless RAT handover occurring. Therefore, supporting dynamic mobility becomes one of key issues for 4G research. For HWN*, we propose to address the mobility management problem through cross layer handover and routing algorithms that optimise the system performance based on fair resource sharing, QoS, Grade of Service (GOS) and minimise the handover delay for roaming MTs.

This paper begins with a hybrid network review, including possible network deployment scenarios and theoretical network dimensioning analysis. In *Section III*, motivated by a QoS design criteria, the service class concept is introduced. We then present cross layer inter and intra network handover algorithms that consider both layer 2 (Media Access Layer) and networking layer issues in *Section IV*. The modifications of a previously proposed cross layer routing algorithm is discussed in *Section V*. Finally in *Section VI*, we show simulation results, followed by a conclusion and future work.

II. Hybrid Networks and Related Work

Recently, the IST WINNER project proposed a novel hybrid relay network [3] to setup new 4G standards in Europe. This

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TABLE I
RECENT HYBRID NETWORKS CLASSIFICATION AND SUMMARY

Project	HWN^*	Winner	SOPRANO
Main objectives	Incorporate a MANET to increase system capacity while realising differentiated QoS services	Novel interface technologies for ubiquitous networks	Test CDMA and connect a cellular network with an IP and MANET network
Basic infrastructure	BSON, BSON with RN, MANET, MANET with RN	Unified radio access technology, RN and BS may change transmission range	RNs transfer the traffic from a hot spot to the neighbouring cooler spot or IP nets
Fixed node antenna	Not investigated	Smart antenna / directional antenna	Not investigated
Traffic handover	Heterogeneous network handover with QoS support	Ubiquitous network handover	Not investigated
Call admission	Coordinated admission controlled by BS	Coordinated admission controlled by both BS and RN	Central admission controlled by BS
Routing issues	BS switch and RN assisted traffic diversion	BS and RN switch	BS switch
Load Balance	Multihop based load balancing considering QoS	Not investigated	Multihop load balancing

work mainly focuses on specific radio interface technologies, which are needed for a ubiquitous radio system. The RNs are planed and share same RAT with BSs and MTs to realise dynamic spectrum usage.

Multi-hop Cellular Network (MCN), Multi-Power Architecture for Cellular network (MuPAC), integrated Cellular and Ad hoc relaying system (iCAR), Self-organising Packet Radio Networks with Overlay (SOPRANO) [4] and Hybrid Wireless Network (HWN) [8] are the architecture designs that have been proposed [7] for hybrid networks. The *iCAR* is derived from existing cellular networks and enable the network to achieve theoretical capacity improvement through adaptive traffic load balancing. Excessive bandwidth in surrounding cells can be borrowed for the congested cell through RNs with primary, secondary and cascaded orders. The *SOPRANO* is a scalable architecture that assumes the use of asynchronous Code Division Multiple Access (CDMA) with spreading codes to support high data rate Internet and multimedia traffic. It is similar to iCAR other than IP network support and cross network connection methods. The HWN, without RN support, requires Global Positioning System (GPS) capability to extract geographical location. Each cell operates either in cellular mode or ad hoc mode depending on the MTs topology information from the GPS. Summarised in Table I are the main features for the HWN*, WINNER and SOPRANO architectures. A comparison of the iCar, MuPAC, HWN and MCN can be found in [7].

A. HWN* Architecture and Network Dimensioning

Table II identifies the technologies used and the features considered for each of the four HWN* communication modes. It specifies the physical layer mode, media access method, spectrum usage, mobility characteristics and data rate. Time Duplex Division (TDD) is implemented on all four modes: BSON, MANET, RN supported BSON and RN supported MANET. The propagation model used will be described in *Section V*. For the MANET and RN supported MANET, we implemented the CSMA/CA Distributed Coordination Function (DCF) of the IEEE 802.11 standard. The air interface can be adapted for TDD/CDMA of 3GPP as described in [11], where multiple data rates are achieved by using various spreading codes.

The use of RNs extends the BSON service range optimises cell capacity, minimises transmit power, covers shadowed areas, supports inter network load balancing and supports MANET routing. Theoretically, both the HWN* system capacity and the transport capacity per MT, when compared to a cellular network, should be improved because the RNs provide relay capability as the substitution of a poor quality single-hop wireless link with a better-quality link in encouraged whenever possible. Also a higher end-to-end data rate that could be obtained if a MT had two simultaneously communicating interfaces. Using three scaling approaches proposed in [6], we can implement network/simulation dimensioning and estimate how many RNs should be deployed when the number of MTs changes. The three parameters are the number of RNs m, the number of MTs n and the system capacity C. The asymptotic scaling for the per user throughput as n becomes large is:

$$m \leq \sqrt{n/\log n} \tag{1}$$

The per user throughput is of the order $C/\sqrt{n/\log n}$ and can be realised by allowing only ad hoc communications which does not necessarily need RN support, when:

$$\sqrt{n/\log n} \leq m \leq n/\log n \tag{2}$$

TABLE II
HWN* FOUR COMMUNICATION MODES DEPLOYMENT

	BS celluar network	Ad hoc network	RN supported cellular network	RN supported MANET
Physical layer	Time division duplex	Time division duplex	Time division duplex	Time division duplex
Media access layer	TDMA	CSMA/CA	TDMA	CSMA/CA
Spectrum regulation	Licensed	Unlicensed	proposed to use same spectrum as cellularnetwork	proposed to use share spectrum with unlicensed MANET
Mobility speed	Low, Medium and High	Low	Low, Medium and High	Low and Medium
Transmission data rate	Low, Medium and High	Low	Low, Medium and High	Low and Medium

The order for the per user throughput is Cm/n therefore the total additional bandwidth provided by m RNs is effectively shared among n MTs. Finally, when:

$$n/\log n \leq m \tag{3}$$

the order of the per user throughput is only $C/\log n$ which implies that further investments in relay nodes will not lead to an improvement in throughput and bandwidth optimisation.

III. Service Class Categorisation

For service categorisation, [10] recommends the classification should not be complicated so that the implementation, monitoring and management costs can be kept low. We therefore implement three service classes to describe subscriber behaviour, which are High profile users (HPUs), Normal profile users (NPUs) and Low profile users (LPUs). The HPUs have the highest access priority of the four communication modes in HWN*, and traffic admission for NPUS and LPUs is dependent on the number of ongoing HPUs sessions. We pre-configure NPUs to have a higher probability than LPUs in terms of resource acquisition and this probability is decided by an Association Level (AL) set, which is explained later. In case of network congestion, BSON and BSON RN modes only allocate channels to NPUs when HPUs are fully accommodated, while LPUs sessions are only granted MANET RN access. Inter/intra networks handover are proposed separately to mitigate network congestion, reduce transmission delay and improve per MT throughput,

A MT locally links an application with a service class based on the particular QoS requirement. The choices are flexible as one subscriber may link business voice calls with the HPUs class and Voice over IP (VOIP) calls to the LPUs class. Another subscriber may link all voice and data services to HPUs class when moving at high speed and then change them to the LPUs class when walking on the street. To facilitate efficient simulation, real time collaboration, wireless gaming, and geographic real time datacast applications are associated with the HPUs class; Interactive multimedia, media telephony and rich data applications are linked to the NPUs class; Lightweight browsing, LAN access and file exchange applications are classed as LPUs. However, as HPUs are liable to acquire more channels than NPUs and LPUs, applications such as large volumes of file exchanges are not suitable for the MANET mode, the weighted fairness queueing algorithm proposed in [9] can be considered for further service optimisation for these scenarios.

IV. HWN* Mobility Management

In cellular system, the terrestrial channels involved in a call are being changed when handover happens and this change is only caused by cellular spectrum management. However, the **Handover** procedure within the HWN* context involves the traffic diversion from one network mode to another network mode, or from one RAT to another RAT. Neither 802 groups nor cellular standard organisations provide mechanisms to deal with network interconnection problems until a recent 802.21 ongoing project proposed to make inter networks handover decision based on signal strength criteria.

Self-organised MANETs can potentially become the primary communications network if the distributed management issues could be solved. The RNs implementation should moderate the problem by providing reliable links between ad hoc nodes. At the network initialisation stage, we configure all HPUs, NPUs and LPUs search for ad hoc service by default. The route establishment and signalling for MANET and MANET RN is sent completed before BSON and BSON RN modes, if all four modes are available. Inter/intra network handover is only triggered when essential so as to avoid unnecessary network management expense.

Table III presents the mobility management classification for movement between networks. We assume all fixed RNs are connected with each other through either wired or wireless links, and likewise for BSs and RNs. The handover process between a MANET and a MANET RN is actually a re-routing process but we prefer to translate it as handover for context consistency.

TABLE III
HWN* TRAFFIC HANDOVER CLASSIFICATIONS

	BS cellular network	Ad hoc network	Relay node
BS cellular network	Intra micro/macro/pico handover	Inter network handover done by mobility central controller	RN involved intra network switch
Ad hoc network	Inter network handover done by mobility central controller	traffic multihop re-routing	RN involved traffic multihop re-routing
Relay node	RN involved intra network switch with relay node	RN involved traffic multihop re-routing	RN mesh information exchange

The entity for inter network mobility cooperation is labelled as the **HWN* Mobility Controller** and is responsible for managing the modification of a route in an attempt to maintain or enhance the QoS level. It is located in the BS and the BS periodically exchanges update information with neighbouring BSs and RNs. The MT makes a distributed decision on inter/intra network handover based on information gathered from nearby BSs and RNs, and local estimation. In next subsection we investigate service class oriented mobility management and in section 4.2, we describe the HWN* handover algorithms.

A. Service Class Oriented Handover Management

I. High Profile Users Application

Communications for HPUs requires high data rates and consistent service, the triggers that can initiate the handover from a cellular service to ad hoc service are:

- The need for a higher data rate channel in a limited transmission range; Cellular spectrum congestion or serving cell overload; Subscribers manually change to an ad hoc service; The cellular network is not available due to unexpected reasons Such as no roaming agreement. Activities require service providers to transfer all calls and data to facilitate equipment maintenance and service upgrades.
- The effective Signal to Noise Ratio (SNR) falls below a predefined level,Intra cellular network handover can not be processed due to channel degradation; A handover from a cellular service to an ad hoc service allows the required QoS to be maintained, whilst radiating less power will result in a general reduction of interference, as well as extended MT battery life. A handover to a MANET reduces the intra micro cell, macro cell and pico cell handover rate, while improving the service grade.

The HPUs handover process from an ad hoc service → a cellular service is initiated by the MT's local estimation, based on triggers summarised as:

- MT velocity increases thus the ad hoc link quality degrades quickly; The MT moves away from fixed RN coverage; Inadequate RNs; Lack of security.
- Ad hoc service congestion; Subscribers manually change to a cellular service; No sustainable route for time-sensitive data due to QoS restrictions.

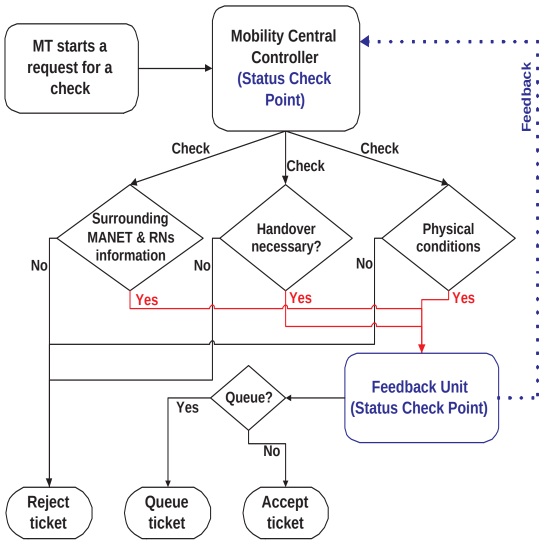

Fig. 2. Traffic handover status check for high profile user from a BSON to a MANET

To obtain an effective handover process, while reducing the unnecessary handover rate, after the MT local estimation, we propose to setup a dedicated **Status Check Point** embedded in the **HWN* Mobility Controller** where the necessary measurements are taken and then fed back to the handover algorithms of the nodes involved. The check result indicates the likelihood of a handover, which depends on interference level and physical layer information such as Bit Error Rates (BER), velocity, buffer size, etc. Since the HPUs applications have higher priorities over NPUs and LPUs, subscribers from this profile are more likely to get a pass ticket from the **Negotiation Unit** (Figure 3). If an acceptance ticket is not issued, the MT will not use the status check data to request continuing with the handover process unless the status check point data necessitates handover. Then the mobility controller will decide to accept, decline or queue the MT handover request.

Figure 2 illustrates an example of the **Status Check Point** handover operation from a BSON to MANET, which is the second step of the HWN* inter network handover algorithm, as shown in Figure 5. At the check start, a MT examines whether one or more conditions are violated, the required information is derived from the feedback unit, which concludes whether

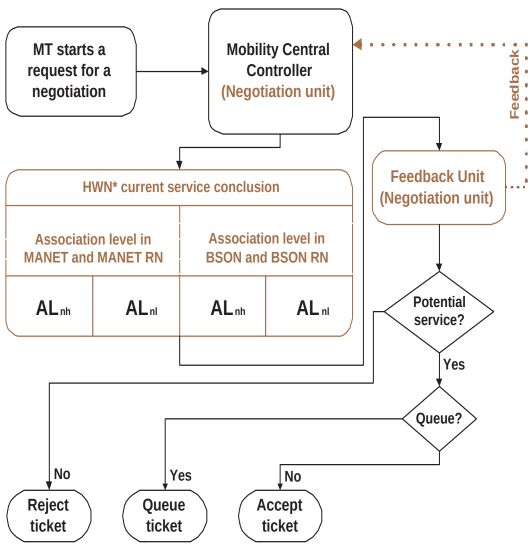

Fig. 3. Negotiation process for normal profile user from a MANET to a BSON

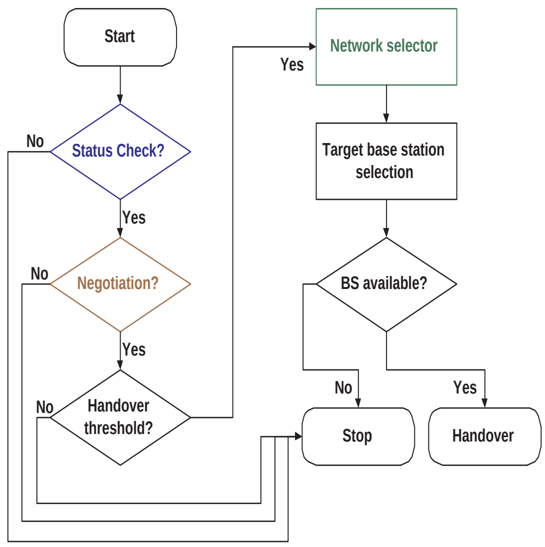

Fig. 4. Intra network handover flowchart for BSON and BSON RN modes

the MT should be switched to the MANET or not. A handover is necessary if the MT passes all three condition checks. The feedback unit will issue an acceptance ticket or queue the handover message when system is busy. Any condition violation results in an immediate handover termination.

II. Normal Profile Users Application

The NPUs applications are expected to be the most heavily used service class in HWN* as voice communications will be still the predominant traffic type. For better QoS, subscribers may prefer to switch from an ad hoc network → a cellular service. After securing a pass ticket in the **Status Check Point**, NPUs applications will go through another process managed by the **Negotiation Unit**, which is a resource sharing monitor for HPUs, NPUs and LPUs and this process is the third step of the inter network handover algorithm, as shown in Figure 5.

Figure 3 shows an example negotiation process for a NPUs application handover from a MANET → a BSON. The mobility controller first updates the channel status table, then the Association Level (AL) between user classes are decided and fed back to the **HWN* Mobility Controller**. (The AL is a set of parameters monitoring channel availabilities, an AL that scores higher than the threshold means that the channels are already occupied by ongoing sessions). We subclassified the AL set into the AL in the BSON, BSON RN, MANET and MANET RN. AL_{nh} stands for the association between NPUs and HPUs, while AL_{nl} is the association between NPUs and LPUs. The inter network handover continues when the NPUs' AL score is within the threshold. The handover triggers for NPUs applications are similar to HPUs applications except for the QoS requirement.

III. Low Profile Users Application

The fixed RN assistance provides a practical ad hoc service solution. The LPUs application types are short voice calls, web browsing and lightweight data transfer. These Applications will be mostly served by MANET and MANET RN modes during the simulation investigation.

The LPUs inter network handover process in **Status Check Point** and **Negotiation Unit** is similar to NPUs handover process. The **Negotiation Unit** first determines the AL_{ln}, AL_{lh} for the four network modes, respectively, and then continues handover process. The triggers for inter network handover or intra network re-routing include: topology changes, MT routing failure, security etc. Based on traffic predictions, providers should change a fixed RN's position in order to fulfill service requirements.

B. Handover Algorithms

Time-sensitive multimedia application has restrictions on end-to-end transmission delay, while FTP data transfer needs a minimum guarantee on packet losses. Further actions such as channel transfer and re-routing are required before service termination. The handover algorithms in HWN* should allow subscribers seamlessly move without dropping their communications and considers differentiated QoS issues, for example, the QoS guarantee for HPUs that agree to pay more than NPUs and LPUs. We discuss two handover types. An **Intra Network Handover** occurs when a MT enters into another entity that belongs to the same network while an **Inter Network Handover** happens when a MT leaves the serving network and communicates with another entity that belongs to a different network.

The flowchart in Figure 4 shows the handover algorithm for a BSON intra network handover (where the serving BS is changed) and BSON RN intra network handover (where RN participates in traffic relaying and the serving BS is changed). For all user classes, the intra network handover is selected before considering inter network handover. After obtaining pass tickets from the **Status Check Point** and the **Negotiation Unit**, the **Network Selector** entity embedded in the mobility controller informs the MT if the RN should participate or not, then the MT makes a local decision. We summarise the handover steps as follows:

1) For N MTs, $0 < i < N$, sort MT_i in descending order

based on weighted calculations involving service class, QoS requirement and service urgency
2) Order the MTs in the handover queue from higher weighted applications to lower weighted applications; Service the first MT in the queue, for K triggers, $0 < j < K$, calculate $Trigger_j$ and decide whether an intra network handover is required
3) If the media access constraint in surrounding BSs, RNs and MTs are not violated, continue; Handover the sessions, or acknowledge it as an intra handover failure; Fail all handover requests which do not pass the checks, for N=N-1, go back to step 1

The inter network handover is a switching process between ad hoc and cellular services. The associated algorithms are shown in Figure 5. Similar to the intra network handover, the **Status Check Point** is activated to avoid extra expense, and the **Negotiation Unit** keeps monitoring the channel availability status and updating the AL instantly to grant or reject handovers. The **Network Selector** always tries to divert the traffic back to intra network handover. Once it confirms that the intra network handover is not possible, if the MT is currently communicating in ad hoc mode, the selector searches available BSs in neighbouring cells. If the MT is in cellular mode, it looks for either direct communication with the other MT or searches for a fixed RN to instigate two hop communications (We currently only investigate the MT → RN → MT scenario and leave multihop pure ad hoc communication for further research). The steps are described as:

1) For N MTs, $0 < i < N$, sort MT_i in descending order based on weighted calculations involving service class, QoS requirement and service urgency
2) Order the MTs in the handover queue from higher weighted applications to lower weighted applications; Service the first MT in the queue, for M triggers, $0 < j < M$, calculate $Trigger_j$ to determine whether a handover is required
3) Try to divert the sessions to **Intra Network Handover** before **Inter Network Handover**; Check the media access constraint, then the MT makes a handover decision; Fail all handover requests that do not pass the checks, for N=N-1, go back to step 1

V. Adaptive Routing Algorithm

Previously, we proposed the cross-layer routing scheme, Adaptive Hybrid Routing with Relay Station (AHRRS) [1]. The results indicated that the algorithm allows upper layers to efficiently adapt their communications strategies to varying link and network conditions while the resulting flexibility helps to improve access speed, end-to-end delay and dynamic resource management performance. The new Service Class Oriented Routing (SCOR) algorithm is derived from the AHRRS scheme, which aims to maximise the ad hoc resource utilisation, increase the network capacity and maintains service provision.

The transmission model defines the methods that nodes employ for communicating with one another. In SCOR, we only consider the *One Hop Ad-Hoc Transmission Model* and

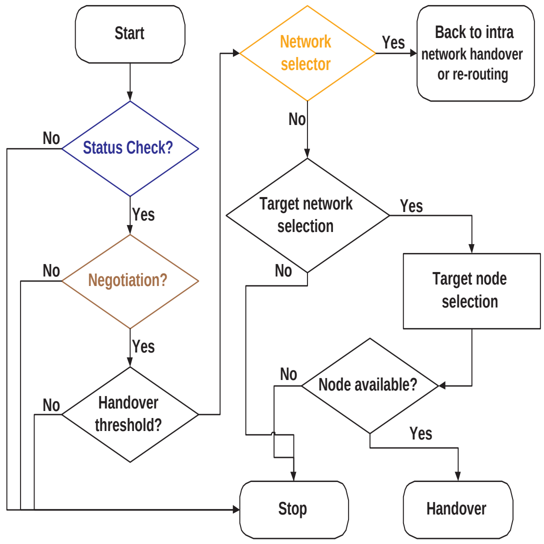

Fig. 5. Inter network handover flowchart between ad hoc and cellular services

Two Hop Combined Transmission Model (MT ⇔ RN ⇔ MT). During ad hoc intra network traffic handover, the MT receives the SIR measurement of the link between the possible serving RN and itself, $SIR_{MT.RN}$, from the BS. It also locally measures the link SIR between the other MT and itself, $SIR_{MT_1.MT_2}$, if within the communication range. Then the MT calculates the one-hop spectral efficiency η_{one} and Two-hop spectral efficiency η_{two} to decide on a new route. The link bandwidth between two adjacent nodes in a pure MANET is usually equal to or better than two hop connection. However, a fixed RN provides infrastructure support with better bandwidth and channel quality. A MT may prefer to transmit its packet to RN, rather than using direct communication with the other MTs. (Problems such as hidden terminals or exposed terminals no longer need to be considered as fixed RNs acknowledge the existence of each other). Therefore, when calculating spectral efficiency, we introduce a **Route Weight Factor** for each RN denoted by R and $0 < R \leq 1$. A busy RN tends to use a smaller R while a contention free RN is given a R near to 1.

Cross layer coordination considering differentiated service classes is another design objective of the SCOR algorithm. A blocked session from any service class by channel admission control or resource allocation will be given other network access opportunities through the traffic diversion process. The scheme organises relay links into link groups where applications with high QoS expectations are likely to access the stable link group and low QoS applications are mostly accommodated in normal link groups. A general routing process can be described as follow:

1) For N MTs waiting for re-routing, M RNs, $0 < i < N$, $0 < j < M$, calculate $SIR_{MT_i.RN_j}$ and $SIR_{MT_i.MT_d}$, where MT_d refers to the destination MT
2) For N MTs, $0 < i < N$, Sort MT_i in descending order from high request to low request based on weighted calculations involving service class, QoS requirement and service urgency, then process the first MT request
3) Check direct communication media access constraint

TABLE IV
CHARACTERISTICS OF QOS DIFFERENTIATED USERS

	Low profile user	Normal profile user	High profile user
Portion of arr. req.	Voice 20% Web 10% Video 5%	Voice 15% Web 8% Video 10%	Voice 10% Web 7% Video 15%
	***Voice* Dwell / Session time: 60s / 120s**	***Web* Dwell / Session time: 120s / trace**	***Video* Dwell / Session time: 120s/240s**

and relay link groups status to make a routing decision; Fail all invalid routing requests, for N=N-1, go back to step 2

VI. SIMULATION AND RESULTS

We use Transmission Control Protocol (TCP) since most web services consist of TCP flows and it is reasonable to presume that traffic due to MT web service will not deviate from this behaviour. The video codec is imported into the OMNET++ and we generalise all video streaming as real-time services, while all web transports are referred to as non real-time services. Table IV shows the QoS profile used consisting of 30% 64 kbps streaming video, 45% general voice calls and 25% non real-time web services according to the 3GPP [11] specification. The service request portion is distributed and shared among these three user classes.

We randomly distribute the MTs in 13 regular hexagonal cells (1km length, 2.6 km^2)in an 8 km X 8 km grid. The BS is located in the centre of each cell, and each cell owns a RN located at a random position. From 300 to 1300 MTs are scattered in the grid to simulate varied scenarios. To ensure that the same cellular frequencies are repeatedly used the cellular network, 7 frequencies are allocated to each cell and 128 channels are available on each BS.

The MT travels from 0 to 80 km/hour since a relative speed higher than 160 KM/hour is not adaptable for the 802.11 radio propagation model, which has limited compensation for channel fading. Typical simulation parameters are used [13] - the log-normal standard deviation σ is set as 10 dB, shadowing correlation distance χ_s is set to 50 m, and the mean SIR value r_d is set to 17 dB. The default energy model provided by OMNET++ is implemented, specifically, for a 250m transmission range the transmit power used is 0.282W. The transmit power used for a transmission range of d is proportional to d^4.

A. Mobility management and Routing Performance

We have used OMNET++ to simulate the HWN*, an ad hoc network with AODV routing protocol and a TDMA cellular network. The handover algorithm referred to as plain handover, for the TDMA network and which operates as follows: a MT establishes communication with a specific BS on a particular channel. When the MT travels to another cell, and if there are channels are free in that BS's cell, the MT then transfers the communication to this BS, otherwise this attempt at handover is marked as a failure. AODV routing failures (excluding route establishment problems due to no relay node being available) are also translated as handover failures for comparison purposes. Figure 6(a) and 6(b) show the load carried per cell and the effective load carried against grade of service (GOS) for the three handoff algorithms, which are traffic management plus SCOR in HWN*, plain handover in the TDMA network and AODV in the MANET. We define the GOS as,

$$GOS = \frac{\lambda_n B_n + \lambda_h P_h}{\lambda_n + P_n} \quad (4)$$

where λ_n is the mean new session arrival rate, λ_h is the mean handover session arrival rate, B_n is the blocking probability of a new session, and P_h is the probability of handoff failure. The results show that even in the complicated HWN* system, traffic management plus ADCR performs significantly better than the other traffic transfer mechanisms. At a GOS of 0.03, which is a typical system performance goal, the total load carried by the HWN* is approximately 11.6 Erlangs compared to 9.4 and 7.9 Erlangs for the other two schemes. It also yields major gains in the effective load carried, at a GOS of 0.03, the total effective load carried by the HWN* has improved by approximately 1.6 and 3.8 Erlangs as compared to the other two networks. We note that increasing GOS (> 0.3) in Figure 6(b) leads to reducing effective carried load since the handover overheads greatly increase, therefore the handover upper limit in HWN* should be set low to mitigate this tradeoff.

Figure 7 shows the session blocking probabilities for Poisson modeled MTs entering the simulated MANET, the MANET with RN, the TDMA network and the HWN* under various traffic loads. It is observed that the ad hoc system presents the worst performance, followed by the MANET with RN, the TDMA network and the HWN* have the lowest session blocking probabilities. The poor results of the ad hoc system can be attributed to frequent topology changes, unstable links and service inconsistencies. Once a network is assisted by a RN the session blocking probabilities are largely reduced. The HWN* low session blocking rate also indicates that more media resources are reserved and granted to service applications admissions.

We also simulate simplified traffic management process for the WINNER and the SOPRANO projects, respectively. For WINNER, through cooperative relaying algorithm, the RN operates full resource management functions like a cellular

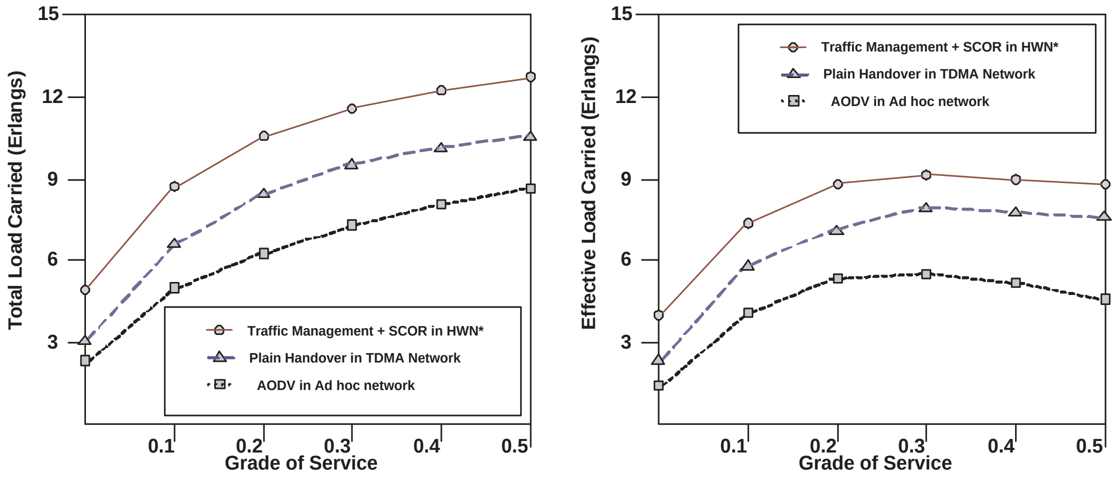

Fig. 6. Total load carried and effective load carried against GOS.

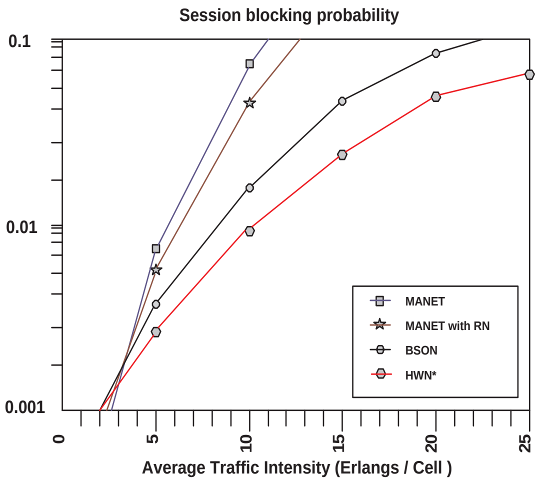

Fig. 7. Session blocking probabilities

BS does. However, for distributed SOPRANO, the routing calculation is the sole responsibility of the local MT, thus, we implemented minimum energy routing protocol as recommended in [15]. Figure 8(a) shows the probability curves of the handover blocking for a new session against the average load offered. We observe that there is a significant improvement in the handover blocking performance for the HWN* traffic management plus routing, compared to the cooperative handover in WINNER and the minimum energy routing in the SOPRANO. From Figure 8(a), at 15 erlangs average offered load, the corresponding session blocking probabilities are 0.023, 0.037, and 0.059. Figure 8(b) illustrates the probability of a forced termination against average load offered. We define a forced termination is when a session is forced to terminate due handover failure and media access failure (caused by traffic congestion). We see that the HWN* system exhibits the best performance when compared against WINNER and SOPRANO, in which no congestion control mechanisms are implemented. For example, at 15 erlangs average offered load, the forced termination probabilities are approximately 0.056, 0.128, and 0.153, respectively. This represents an almost threefold improvement over the performance of the other two systems.

B. *User Classification Evaluation*

Experiments are also conducted to verify that the proposed mobility management and SCOR algorithm meet the goal of providing QoS differentiation among different users based on their class profile. To setup a comparison benchmark, we simulated a simple HWN* without any dedicated resource management and routing algorithms. In this network, each session has the same privileges when accessing the media resource and fixed plan is deployed for RN and BS coordination. The arriving packets are accommodated on first-come-first-serve basis until all available channels have been used. A MT terminates the handover process when it can not find an alternative route or no free channels are available in roaming BS. Figure 9 shows the probability curves for handover blocking, it again shows performance improvements for the HWN* with user class classification. This improvement is marginal when the system is heavily loaded. It is interesting since dynamic channel balancing usually presents even or worse performance compared to fixed channel balancing place under high traffic load.

Table V shows the average successful handover probabilities against traffic loads offered. It can be seen that different results are experienced by user applications in different service classes and for unclassified users in simple HWN*. Under low and medium traffic intensities, the handover rates are similar among HPUs, NPUs and LPUs, since sufficient resources are available and LPUs are not largely affected by HPUs and NPUs communications. However, in the high traffic intensity case, HPUs and NPUs applications encounter large resource competition, which consumes a considerable fraction of the radio resource. This may adversely affect the performance of LPUs, in particular when a HPU and NPU traffic hot spot occurs, LPUs are pushed to use the MANET and MANET RN modes, where the traffic transfer process are comparatively unstable compared against the BS and BS RN modes.

TABLE V
AVERAGE SUCCESSFUL HANDOVER COMPARISON OF DIFFERENT USER CLASSES

	HPUs	NPUs	LPUs	Simple HWN*
5 Erlangs/cell	100.0%	100.0%	99.5%	97.6%
10 Erlangs/cell	100.0%	99.2%	98.9%	93.2%
15 Erlangs/cell	99.3%	99.0%	97.7%	91.1%
20 Erlangs/cell	99.1%	98.4%	96.5%	88.5%
25 Erlangs/cell	98.3%	97.1%	95.1%	86.8%

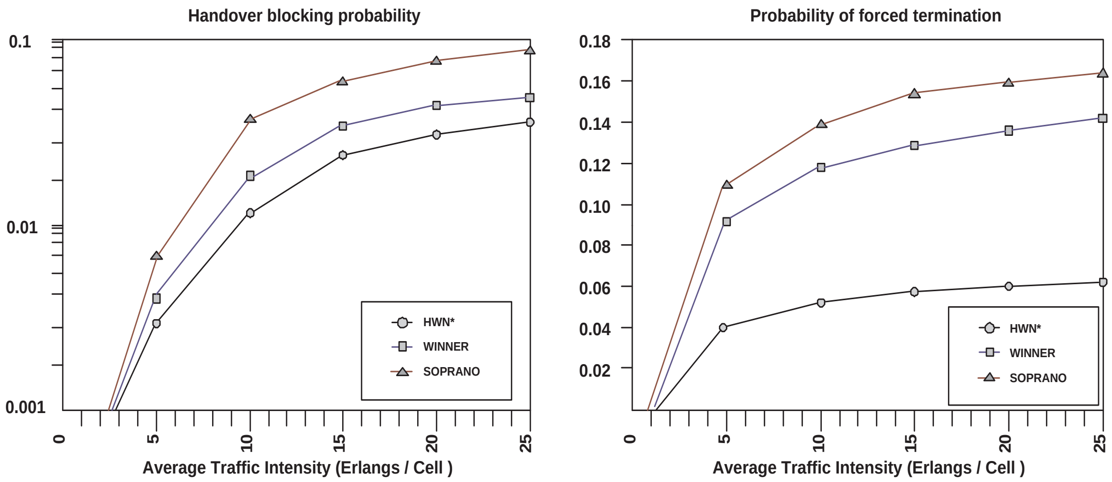

Fig. 8. Performance comparison of the HWN*, WINNER and SOPRANO

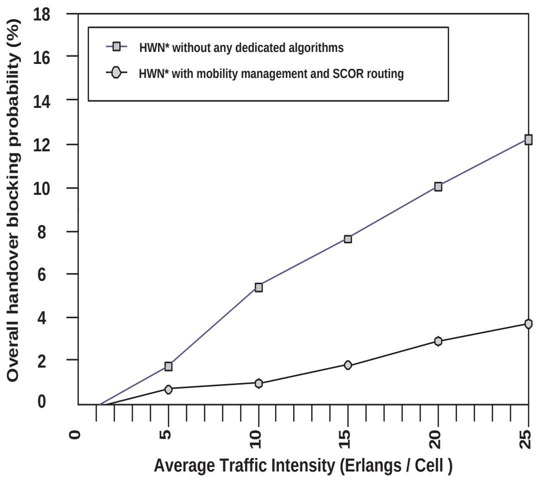

Fig. 9. Handover blocking probabilities

VII. CONCLUSION

In this paper, mobility management issues for HWN* consisting of a MANET, a cellular network and dedicated RNs are investigated. To tackle the resource management difficulties, service class based handover and cross layer routing co-investigation approach is adopted, while the simulation results indicate significant improvement on overall session blocking probability, GOS, congestion control and QoS of an individual user class. Future work will look at the resource sharing algorithms based on computational intelligence and the investigation on RN positioning will be also addressed to facilitate a practical fixed relay node placement plan.

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