



VTC 1994

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"Creating Tomorrow's Mobile Systems"

**1994 IEEE 44th
Vehicular Technology
Conference**



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Chairman's Message

The 44th Vehicular Technology Conference, VTC 1994, is for the first time held outside of North America, in Stockholm, capital of Sweden. Sweden is one of the pioneering countries in the world for mobile communications, and actively engaged in developing the communication systems of the future. The Conference Committee has chosen the motto **Creating Tomorrow's Mobile Systems** to reflect the advanced development work going on, not only in Sweden but all over the world, aimed at future mobile communication systems, that will be reported during the conference. The timing of the conference matches well with the European progress in launching new digital cellular and cordless systems such as GSM, DCS 1800 and DECT.

The conference has received more contributions than ever before, an increase of more than 50 %. In order to accommodate as many as possible of these contributions the Technical Program Committee has greatly increased the size of the poster sessions. To these sessions contributions has been referred that will specially benefit from a more intimate presentation in relaxed surroundings. Concurrent with the poster sessions are the traditional parallel oral sessions. Almost 400 papers will be presented during the conference. You will also find morning tutorials.

In addition we are happy to continue the tradition with two Luncheon Keynote Speakers and an Evening Panel Discussion. On Wednesday June 8, Dr. Åke Lundqvist from Ericsson will talk about *Personal Communication challenges in US and Europe* and on Friday June 10 Robin Potter from Mercury One-2-One will discuss *The role and experience of new operators in 1800 MHz*. On Thursday June 9, there will be the Awards Luncheon, followed in the evening by a Panel Discussion about *PCS Technologies*, chaired by Dr. William C.Y. Lee from PacTel Corp.

It is a great pleasure for me, on behalf of the IEEE Vehicular Technology Society, the Swedish Section of IEEE and the Swedish Society of Electrical Engineers, to welcome you to Sweden and Stockholm.

A handwritten signature in black ink, appearing to read 'J. Uddenfeldt', with a long horizontal flourish extending to the right.

Jan Uddenfeldt
Chairman VTC 1994

IEEE VTC 1994

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Conference Schedule IEEE VTC 1994

Tuesday
June
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City Tour 15.30 - 17.00
Registration 16.00 - 19.00
Welcome Reception 17.30-19.00

8.00-9.00

Tutorial:
Road
Transport
Informatics:
Socrates,
ARENA

9.15 - 11.45

A11: DS-CDMA Field Tests
B11: Handover I
C11: Propagation: Multipath
D11: Equalization I
E11: Digital Mobile Systems I
F11: RTT Infrastructure
G11: Implementation

11.45 - 13.15

Luncheon
Keynote
Speaker:
Dr. Åke
Lundqvist,
Ericsson.

13.15 - 15.15

A12: DS-CDMA System Performance I
B12: Handover II
C12: Propagation: Models
D12: Equalization II
E12: Digital Mobile Systems II: GSM
F12: RTT Systems and Components I
G12: Transmitters

15.30 - 17.30

A13: DS-CDMA System Performance II
B13: System modelling
C13: Propagation: Microcells
D13: Receiver Techniques
E13: Digital Mobile Systems III
F13: RTT Systems and Components II
G13: Device Technology

Evening

Civic
Reception
City Hall
19.00 - 21.00

Wednesday
June
8

II: Poster sessions: CDMA, Antennas, Frequency Hopping, Radio Networks, Indoor, Input-output Systems

Tutorial:
Third
Generation
Mobile
Systems

A21: DS-CDMA Demodulation
B21: Radio Resource Management I
C21: Propagation: Indoors
D21: Diversity Combining
E21: Digital Mobile Systems IV
F21: Vehicle Electronics
G21: Packet Access I

Awards
Luncheon

A22: DS-CDMA Joint Detection
B22: Radio Resource Management II
C22: Propagation: Microwaves
D22: Coded modulation
E22: Wireless Architectures
F22: Trains
G22: Packet Access II

A23: DS-CDMA Interference cancellation
B23: Radio Resource Management III
C23: Propagation: General
D23: Modem Performance
E23: DECT
F23: Frequency Hopping
G23: Packet Access III

Panel
Discussion
18.00 - 20.00

Thursday
June
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II: Poster sessions: Modulation, Equalization, Diversity, Speech coding, Video, Implem., Wireless Data, Packet Access, Coding, Vehicle Electronics/Trains

Tutorial:
Future
Network
Architectures

A31: ARQ-Protocols
B31: System Capacity I
C31: Antennas: Arrays
D31: Modulation
E31: Wireless Networks
F31: Multicarrier Techniques
G31: Speech/Channel Coding I

Luncheon
Keynote
Speaker:
Robin Potter,
Mercury
One-2-One

A32: Wireless Data
B32: System Capacity II
C32: Antennas: General
D32: Indoor Transmission
E32: Mobile Satellites
F32: Multicarrier Modems
G32: Speech/Channel Coding II

Friday
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II: Poster sessions: Propagation, System Capacity, Handover, Multiple Access, Cellular

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Site Hand Off Operation in a SmartZone System

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Abstract: In recent years, trunked land mobile radio system technology has grown from commercial Specialized Mobile Radio (SMR) applications into very sophisticated private system applications. Many of these private trunked radio systems provide communications over very large geographic areas such as entire states. Some wide area communications systems, as designed by Motorola, allow nearly seamless communications between sites within the total geographic area and are marketed by Motorola under the trademark SmartZone.

Subscribers in a SmartZone™ multi-site trunked communication system have the ability to accomplish site hand offs without needing the fixed end equipment to notify them when to switch to another site. The subscriber units accomplish this by utilizing Received Signal Strength Indications (RSSI) in the hardware and with software algorithms to smooth out the raw RSSI data collected by the radio from the control channel. Preferences can be placed on specific sites which will cause the subscriber units to switch towards/away from specific sites. This process of having the subscriber units determine when it will be beneficial to switch to another site eliminates the additional signaling on the control channel which would be needed to keep the subscriber units at the optimal site if the site switching decision was performed at the fixed end.

I. BACKGROUND

A. HISTORY

Since the mid-1970's, trunking techniques have been used on radio channels in the 800 MHz band and more recently in the 900 MHz band in the United States [1]. The majority of these radio systems are what the FCC has designated as Specialized Mobile Radio (SMR). A SMR licensee is generally allocated 5-20 channels, each made up of a pair of frequencies, to provide half-duplex two-way group dispatch communications between the subscribing customers. A Trunked SMR system is differentiated from

cellular communications in that the primary SMR service is this half-duplex one-to-many group dispatch whereas the primary cellular service is one-to-one full duplex telephone calls.

B. BASICS

A trunking system supports the dispatch communications needs for mobile and portable radio users that are normally organized into groups. A typical SMR system group may be comprised of 10 mobile radio units. A system may contain 100 groups. When one of these radio units initiates a transmission, the trunking system automatically picks an available channel from the pool of channels allocated to the system licensee and assigns it to the transmitting unit and its associated group members as well. The idle radio units in the group are automatically directed to the assigned channel so that they may receive the traffic from the group's transmitting radio unit.

The control channel is used by the subscriber units to monitor for Outbound Signaling Words (OSWs) which will direct the subscriber unit to a specific frequency where the initiating radio is transmitting. The initiating radio will first request a channel by means of transmitting an Inbound Signaling Word (ISW). The central controller (primary call processing unit of the fixed end equipment) will process the request and assign a channel for the call.

The central controller will convert the ISW into an OSW and will broadcast this OSW over the control channel. The requesting unit will go to the assigned voice channel and proceed to transmit audio. The fixed end equipment will turn around the inbound audio and re-transmit it outbound after superimposing a low speed data word. The low speed data word is used by the receiving units for verifying that the unit is on the correct frequency for this specific call.

C. NEW TRUNKING SYSTEMS

While the earlier trunking radio systems were SMRs providing shared communications resources for many unrelated users, many of the trunking systems are now

finding application in private systems such as public safety, government, utility, transportation, and industrial users. Building upon the signaling capabilities required to handle the routine group dispatch communications, several enhancements have been made to trunking systems to enable them to meet the demanding communications needs of these private systems users.

Since many of these private users have operating areas much larger than the average coverage area of one trunking system, several have been combined together to form a larger composite system. A new class of wide area trunking systems uses what is called Dynamic Site Assignments. As the radio units roam about, they will automatically register with the trunking site that is currently servicing them. This registration information is tracked for the entire network of systems such that only the sites servicing a particular group need activate a channel resource when a member of the given group desires to communicate to its group members. Sites are assigned dynamically as the active groups move about from site to site. Such a system can reduce the over-all number of required channel resources found at each site as compared to other wide area system alternatives such as simulcast.

This new class of trunked system requires the subscriber units to be capable of nearly seamless communications between the sites. The sites have partially overlapping RF coverage between them. This overlapping coverage gives the subscriber unit multiple potential communicating sites with which to transmit on. The subscriber units in this new class of trunked systems has the capability to accomplish site switching without the need for the fixed end equipment to monitor the transmission of a specific unit and make decisions to switch sites. The site switching determination is accomplished totally within the subscriber unit.

II. SITE SWITCHING COMPONENTS

A: RECEIVED SIGNAL STRENGTH INDICATIONS (RSSI) HARDWARE

The RSSI level is a signal strength output from the intermediate frequency (IF) amplifier circuitry that is part of every subscriber unit. The RSSI circuitry is designed into the IF amplified integrated circuits in SmartZone™ subscriber units. This is a direct and absolute measurement of RF signal strength. The output DC voltage from the IF is an analog signal which is routed to an eight-bit A/D converter which can be read by the microprocessor in the subscriber unit. Because there are small unit to unit and temperature variations, the RSSI is not an instrumentation accuracy measurement that would be specified in a piece of

test equipment. An exact value is not needed in this application, only a comparison between control channels sampled by an individual subscriber unit. The RSSI voltage vs. RF strength is linear in the usable range. Figure 1 shows the data collected from 10 subscriber units in a lab environment. The RSSI accuracy, however, is more than adequate to make intelligent signal strength control channel decisions in the SmartZone™ system.

B: RSSI FILTERING ALGORITHM

A problem in using the raw RSSI data is that the RF input signal is not always constant but fluctuates around some mean value due to fading and interference. Therefore, the raw signal has to be post-processed in some manner to eliminate errors caused by signal fluctuations. The filtering algorithm used is shown below:

$$F_{\text{new}} = F_{\text{old}} [K] + R [1 - K]$$

Where:

F: filter output value of the signal strength

R: signal strength data value from the current sample

K: filter constant

Time since last update	filter constant (K)
< 8 seconds	0.8
8 - 16 seconds	0.7
> 16 seconds	0.6

Because the filter history data may become stale if the time between samples is large, the use of the filtered data is de-emphasized with time. This is accomplished by using different values for the filter constant dependent on the amount of time since the last RSSI update was done. If the actual time between samples is small, the filtered data will be emphasized more with respect to the current sample. This is done because the filter data is still a fairly accurate representation of the true signal strength. Long periods without sampling will cause the filtered RSSI value to be

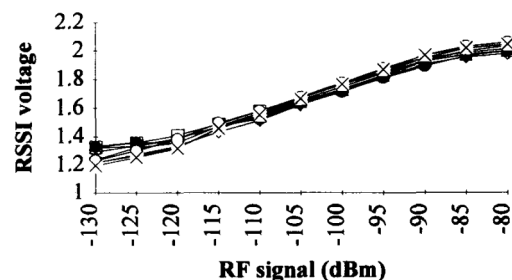


Figure 1: SMARTZONE™ RSSI CURVES

less accurate than the current sample. When a long time period has elapsed, the previous filtered RSSI value should be de-emphasized with respect to the current RSSI sample.

The filtering of the signal strength for the adjacent sites makes the subscriber units much more efficient in selecting a new operating site than if an instantaneous signal strength reading was maintained as the basis for an adjacent site rating. By using this filtration method, the subscriber unit shall be able to reduce the affects of temporary abnormalities in signal strength readings (caused by shadowing, fading or general Raleigh distributions). The filtered RSSI values will maintain a more accurate representation of adjacent site signal strength with respect to the current site's RSSI.

The RSSI values acquired after using the filtering algorithm are categorized into one of four ranking levels (Excellent, Good, Acceptable, and Poor). Both the filtered RSSI value and the ranking level for each site will be maintained in the subscriber unit's database. If the subscriber unit has not been able to sample a control channel in it's list, the ranking level for the non sampled entry will be ranked between the acceptable and poor ranking levels. The five levels allow for a simplified algorithm to be utilized when attempting to rank the sites.

C: RSSI SAMPLING

The signal strength ranking levels are determined by leaving the current site's control channel and sampling the RSSI of adjacent site control channels. The subscriber unit will also sample the current control channel's signal strength prior to re-programming it's synthesizer for a different site's control channel. Since leaving the current control channel could result in missing important call information, the subscriber unit will use an inactivity timer to determine when the unit has been continuously inactive on the control channel for a specified period of time.

The inactivity timer is a means to determine that the subscriber has not been involved in a conversation as either the transmitter or receiver of a conversation. If the subscriber unit becomes active in a voice call, the activity timer will be disabled. When the subscriber unit returns to the control channel, the inactivity timer will be enabled and re-initialized to a predetermined value. When the inactivity timer expires, the unit will perform RSSI signal strength samples on as many adjacent sites as possible, in 8 OSW time frames.

The time restriction is such that an individual subscriber unit will not miss any individual unit directed OSWs.

These types of OSWs are transmitted only four times separated by at least one single word OSW. In a worst case situation, a subscriber unit will exit the current control channel in the middle of the first of four repeat OSWs, but will be back on the current control channel in time to receive the last of the four repeat OSWs. This worst case situation is depicted in figure 2.

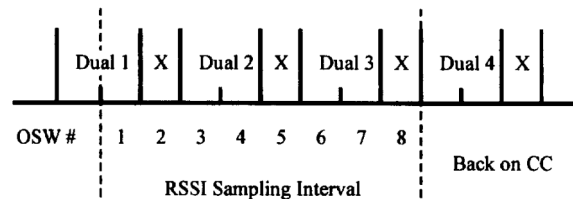
D: PREFERRED SITES

In addition to signal strength information, sites may also be ranked based upon preferred site information. Preferred Site Operation is a SmartZone™ subscriber unit feature that allows a subscriber unit to search for an alternative preprogrammed preferred site which is operationally preferred over the current site. Four distinct levels of preference can be programmed into a subscriber unit for different sites. The preferred site operation feature helps use channel resources efficiently by steering specific user groups to sites which will reduce the number of sites needed to complete a specific conversation.

The four levels of preference are defined as follows:
Always Preferred: The subscriber unit will use this site if it has at least an acceptable signal strength even if the site enters site trunking mode. This method should be used if the preferred site chosen is the place where most, if not all, the communications for this unit need to take place and the loss of wide-area trunking capabilities is not considered a crucial factor for the system users.

Preferred: The subscriber unit will use this site if it has at least an acceptable signal strength rating and is in wide area trunking mode. This method should be chosen if wide-area trunking capabilities is more important than operation at an always preferred site which may be in site trunking mode.

No Preference: The subscriber unit will use the site with the best signal strength rating. This is the default setting for subscriber units. This method is the normal method of operation when there are no special situations that need to be accounted for in regards to operation under site trunking conditions, distributing traffic loading or conserving



Where: X is the background OSW

Figure 2: Worst case depiction for missed OSWs due to RSSI sampling.

repeater resources.

Least Preferred: The subscriber unit will avoid this site unless no other sites with at least an acceptable signal strength are available for use. This method can be used to distribute subscriber units amongst two or more sites in order to avoid overloading a central, common site that is being overlapped by surrounding sites.

E: SITE RANKING

The adjacent site ranking value is determined by incorporating data from the signal strength rating, preferred site status and site validity information. The site validity information is used to characterize the condition of the specific site in question. Some of the validity information maintained is whether or not the site has failed bit synchronization (i.e. the frequency of the control channel at an adjacent site was of sufficient strength but the subscriber unit could not lock onto the bit synchronization pattern, therefore it is unusable), whether or not the site is in a failure mode, and whether or not an adjacent site OSW has been received for this site. The above mentioned validity information is not an exhaustive list of information that is maintained in the database within the subscriber units.

By incorporating all of the binary values, a ranking is created for each site included in the adjacent site list. This list will contain all of the adjacent sites ordered from highest to lowest ranking. If two sites have an identical ranking, the site with the strongest RSSI value will be placed first in the list. The adjacent site ranking is created in a two byte field as follows:

Most Significant Byte

0	V1	V2	V3	V4	S1	V5	V6
---	----	----	----	----	----	----	----

Least Significant Byte

0	V7	V8	P1	P2	S2	S3	0
---	----	----	----	----	----	----	---

Where: The validity bits are defined as V1 - V8

Signal Strength Rating	S1	S2	S3
Excellent	1	1	1
Good	1	1	0
Acceptable	1	0	1
Not Sampled	0	0	1
Poor	0	0	0

Preferred Site Status	P1	P2
Always Preferred	1	1
Preferred	1	1
No Preference	0	1
Least Preferred	0	0

F: ADJACENT CONTROL CHANNEL BROADCASTS

The fixed end equipment will maintain a database that contains a relation of all sites to its neighboring sites. This database will be dynamically updated when information at each site changes. Some of the specific events which may occur at a site that will alter this database are 1) repeaters used for interconnect malfunction, 2) communication link to the site malfunctions, 3) a control channel repeater malfunctions causing the control channel at the site to switch, etc. Information about a site that is adjacent to another will be transmitted down the communication link from the central database. Each of the remote sites will re-broadcast this information in the form of an adjacent control channel OSW. The information sent to the remote sites will contain information about the currently active control channel and also the potential control channels along with information about the other repeater's capabilities within the site.

The subscriber units will process the broadcast information, which is in the form of OSWs, and will modify the subscriber unit's database accordingly. The subscriber unit will make site selections based upon the site's available capabilities.

III. SITE SWITCHING METHODS

A: CONTROL CHANNEL SITE SWITCHES

When the subscriber unit initially power cycles on, it will not look for the best site for operations, but rather, will look for a site that has at least an acceptable signal level. The reason for bypassing the algorithm to find the best site when first applying power to the subscriber unit, is to allow the subscriber unit to start communications at the earliest possible moment. The subscriber unit will eventually migrate to the best possible site for its operations. The migration process (RSSI Update algorithm) incorporates the site switching components mentioned earlier as well as a list of pre-programmed potential control channels which are used within the SmartZone™ system.

The RSSI Update algorithm consists of 1) leaving the current control channel, 2) sampling the signal strengths of other control channel frequencies, 3) re-ranking the elements in the adjacent control channel list, and 4) either returning to the current control channel or switching sites to a better one. The algorithm will proceed when a counter of OSWs expires. This counter is used to signal when the update algorithm should proceed. The RSSI Update algorithm is shown in Figure 3.

```

Reset the OSW counter
Sample, Filter, Rate and Store current control channel
If current site is broadcasting adjacent site OSWs
  Get freq. of next element in adjacent site list
  While (the number of OSWs missed < 8), Do
    Program synthesizer for adjacent site freq.
    Sample, Filter, Rate and Store the RSSI
    Get freq. of next element in adjacent site list
  EndWhile
Else
  Get freq. of next element in pre-programmed list
  While (the number of OSWs missed < 8), Do
    Program synthesizer for potential CC freq.
    If freq. is in adjacent site list,
      Sample, Filter, Rate and Store the RSSI
    Else,
      Sample RSSI
      If (RSSI Rate > Acceptable)
        Rate and Store the RSSI in adjacent
        site list
      Endif
    Endif
  EndWhile
  Get freq. of next element in pre-programmed list
Endif
Re-rank the adjacent site list
If ((current site ranking + 2) <
  top element of adjacent site ranking)
  Program synthesizer for top element's freq.
Else,
  Program synthesizer for current control channel
Endif

```

Figure 3: RSSI Update Algorithm

B: VOICE CHANNEL SITE SWITCHES

Prior Motorola trunked systems mute the audio at the subscriber units after improperly decoding low speed data words. If the situation of receiving improperly decoded OSWs persists, the subscriber unit will leave the voice state and will attempt to re-acquire control channel synchronization. In a SmartZone™ system, the subscriber units will attempt a site switch when low speed words are incorrectly decoded. The change in the algorithm is to assist when a subscriber unit is traveling away from one site towards another site during a long conversation, such as in an interconnect call.

The subscriber unit when traveling away from one site while traveling towards another site will transition to the new site more gracefully if a site switch occurs after decoding bad low speed data words. This condition will prevent a subscriber from muting its audio and then transitioning back to the control channel only to find that the control channel is directing the subscriber unit back to the voice channel. In a SmartZone™ system, the sites have overlapping coverage and the voice channel will degrade prior to the control channel. When the voice channel from site 1 degrades to the point where the audio is producing audio holes, usually this is the point in the transition where the subscriber unit should switch sites.

The subscriber unit will then exit the voice channel and automatically switch control channels to the next best possibility in the list. The site ranking for the prior site will be de-ranked after the site switch. This modified algorithm will allow for a smoother transition between adjacent sites when the subscriber unit is in the voice state.

IV. PRACTICAL RESULTS / SUMMARY

The above mentioned algorithms and filtering methods are currently incorporated into SmartZone™ subscriber units manufactured to be used on Motorola's wide area SmartZone™ communications systems. The theoretical approach has been proven to provide good results with respect to site hand off operation. The methods described have been incorporated into analog mobile and portable units which operate in full duplex or half duplex interconnect. The methodology has been tested on many analog systems in the 800 MHz, 900 MHz, and UHF frequency bands. It has also been tested with simulcast sites within the SmartZone™ system. The methodology has also been tested in mobile and portable units which operate on digital systems in both single site and simulcast site configurations. A major state wide system has been utilizing this site switching methodology since its installation last year.

V. REFERENCES

- [1] Arthur Chrapkowski and Gary Grube, "Mobile Trunked Radio System Design and Simulation," in *Proceedings of the 41st IEEE Vehicular Technology Conference*, May 1991, pp. 245-250.