Quality-based Channel Selection in Multi-channel Radio-over-Fiber System

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Abstract—Radio over Fiber (RoF) is a promising solution for wireless access services by transferring the heterogeneous radio signal via the optical fiber link. However, RoF devices have nonlinear characteristics which create intermodulation products in system. The intermodulation distortion (IMD) interferes uplink RF signals in the presence of coupling between downlink and uplink antennas in the base station (BS). This paper proposed the performance evaluation due to coupled downlink interfere to uplink antenna. The carrier to distortion plus noise ratio (CDNR) is evaluated for all combinations. By using NS3 network simulator, the result shows the best combination achieves better performance. Which coupled downlink interfere in uplink signal can be reduced when amount of downlink packet is decreased.

Index Terms—RoF, IMD, Multi-Channel.

I. INTRODUCTION

The growing reliance on mobile devices and constant communication has encouraged technological advancements in wireless communication. These devices, using high bandwidth multimedia applications, are acceptable. Yet, in the recent years the increasing demand in broadband and heterogeneous wireless communication has brought about a serious problem, the frequency bandwidth shortage.

To cope with this problem, Radio-over-Fiber (RoF) technologies are applicable; it aims to support the growing traffic of heterogeneous wireless air interface by reducing the bandwidth limitation. By using optical signal and then transmits it over an optical fiber link, the system communication modulation between base station and centralized control station can be achieved. In RoF, the centralized control station (CCS) is responsible for control and managing the Radio Frequency (RF) known as dynamic channel allocation (DCA) as shown in Fig.1

The optical fiber has better performance than the coaxial cable link, because of some key advantages: the broad bandwidth and immunity from electromagnetic interference. While on the other hand, intermodulation distortion is generated by the nonlinear devices when multiple radio frequency channels are simultaneously transmitted.

To analyse the intermodulation products, the intermodulation in satellite communication has been scrutinised in [1]. The effects are showed when the number of carriers are increasing. [2] studied the effect of intermodulation distortion when stations is moving in RoF network. [3] proposed the random spacing channel assignment algorithm (RSCA) to reduce the intermodulation distortion performed by nonlinear devices.

In the dynamic channel allocation (DCA), many algorithms have been proposed. The algorithm for relaying networks proposed in [4]. While [5] shown the solution that rely on link budget. [6] propose the comparison of four channel allocation schemes. [7] presented DCA for RoF network.

This paper points out a requirement for radio frequency channel allocation in multi-channel RoF system. The system model and problem are presented in Section II. Section III shows the IMD analysis. The frequency plans are shown in Section IV. Section V shows the mac model. The numerical calculation of link budget is presented in Section VI. Section VII presents computer simulation using NS3 and its results. The conclusion is shown in Section VIII.

II. SYSTEM MODEL

The linearity of system is extremely important. In practice, all of nonlinear responses of optical modulators, amplifiers contribute to transmission impairments.

The intermodulation is produced when two or more different frequencies are beaten in nonlinear devices. Although from this incident, there are many products of the intermodulation are produced, for examples: $2^{nd}$ order, $3^{rd}$ order. The $3^{rd}$ order intermodulation has much affection in single octave transmission system.

Fig.2 shows the IMD problem in multi-channel RoF system. In downlink, two RF signals modulate the optical carrier using electric optical modulator. The intermodulation products appeared at the output of O/E (Optical to Electric converter). Then RF signal and IMD are radiated from transmitting antenna. In uplink, the transmitted signal from the mobile
terminal is forwarded to the centralized control station (CCS). Due to the coupling between transmitting and receiving antennas in BS, the intermodulation products are generated from coupled downlink signal interfere the uplink signals at the output of O/E.

![Diagram of communication system](image)

Fig. 2: IMD between RF up/down link in multi-channel RoF

### III. IMD ANALYSIS

The frequency spectrum of the intermodulation distortion is given by

\[ S_{IMD3}(f) = C_f(S(f) \otimes S(f) \otimes S(-f)), \]

where \( S(f) \) is the input spectrum, \( C_f \) is the third IMD coefficient and \( S_{IMD3} \) is the spectrum of the third order IMD. The operator \( \otimes \) denotes the convolution [8]. We have developed a MATLAB based software to evaluate the IMD components at the other frequency band in arbitrary number of RF carriers. When the number of RF carrier is 5, for example, the frequency spectrum of the third intermodulation distortion is shown in Fig.3.

![Frequency spectrum before and after transmission through nonlinear channel](image)

Fig. 3: Frequency spectrum before and after transmission through nonlinear channel (\( C_f = 0.0047 \))

### IV. FREQUENCY PLANS

Since the frequency of IMD components depends on the active frequencies of desired signal, frequency synthesizer can select active frequency channel. The proposal estimates all of the frequency plan combinations. And then assign the best frequencies with the lowest IMD power to the other active channels. In this analysis, the maximum number of channels is assumed to 11. The number of active frequencies in each base station depends on the number of users. Fig.4 shows the carrier to distortion plus noise ratio performance (CDNR) \( (C_f = 0.0047) \) which is calculated from the average CDNR over all possible combinations. Then, the largest one is selected as the best.

In Fig.4, the best frequencies can avoid interference completely up to 4 channels. In case of more than 4 channels, IMD interference still occurs. As the number of channels increases, the difference between best and worst is converged.

For example, Fig.5 shows one of best combination of frequency plan in case of 5 active channels out of 11. Then calculate the average CDNR in active channels. From the simulation, carrier RF power is 0 dBm, while the variety of IMD power is shown in red colour of Fig.5.

![CDNR with the number of active channels out of 11 channels](image)

Fig. 4: CDNR with the number of active channels out of 11 channels

![IMD power in case of best channel combination](image)

Fig. 5: IMD power in case of best channel combination (red: active, blue: inactive, value: IMD power in dBm)

### V. THE MAC MODEL

The 802.11 standard specifies the use of state machines, which can be classified in three states.

- Carrier Sense/ Clear Channel Assessment (CS/CCA)
- Transmit (Tx)
- Receive (Rx)
Fig. 6: Uplink transmission timeline at base station

Fig.6 shows the timeline at BS in case of uplink signal is interfered by coupled downlink signal. When the uplink signal with coupled downlink signals are transmitted via receiving antenna, and modulate optical carrier, the intermodulation occurs at the CCS and the intermodulation power remains constant. The intermodulation power does not pass through long distance air propagation, the high level intermodulation components are produced. However, the received uplink signal power is smaller than coupled downlink signal when the air propagation distance between mobile and BS is long. So, this IMD occurrence can be considered as a serious problem as shown in Fig.6b.

Fig. 7: Downlink transmission timeline

Fig.7 shows the timeline that downlink IMD interfere. The IMD and transmit signal must be passed to the path loss model which made the IMD power less than transmitted signal power. Hence, IMD in downlink is not a problem.

VI. NUMERICAL CALCULATION OF LINK BUDGET

In this section, the link budget is estimated in order to calculate magnitude of radio coverage area. Table I shows numerical parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient ((C_f))</td>
<td>0.0047</td>
</tr>
<tr>
<td>Number of user per channel</td>
<td>1</td>
</tr>
<tr>
<td>Radio Standard</td>
<td>802.11a</td>
</tr>
<tr>
<td>LD input RF power in downlink</td>
<td>17.0206 dBm</td>
</tr>
<tr>
<td>RF active</td>
<td>5 channels (Best case)</td>
</tr>
<tr>
<td>RF bandwidth</td>
<td>20 MHz</td>
</tr>
<tr>
<td>Propagation Loss Model</td>
<td>LogDistancePropagationLossModel [9]</td>
</tr>
<tr>
<td>Coupling loss (between downlink and uplink antennas in BS)</td>
<td>0 dB</td>
</tr>
</tbody>
</table>

From Fig.5 IMD power only in left frequency band (Channel 1), which is the best frequencies, was used in this simulation. In this case, IMD power of -57.9dBm/20MHz is produced at left 3 frequency bands.

Fig.8 shows the relationship between RF power and distance when downlink and uplink continuous waves (CWs) are simultaneously transmitting. The IMD interfere desired signal only in case of uplink.

VII. THROUGHPUT PERFORMANCE

To demonstrate the behavior of channel selection, the throughput performance is evaluated by using NS3 simulation [10] and MATLAB. Table II shows simulation parameters, while the experiment scenario is presented in Fig.9

<table>
<thead>
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<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient ((C_f))</td>
<td>0.0047</td>
</tr>
<tr>
<td>Number of user per channel</td>
<td>5</td>
</tr>
<tr>
<td>Radio Standard</td>
<td>802.11a</td>
</tr>
<tr>
<td>Data rate of a stations</td>
<td>500 Kbps</td>
</tr>
<tr>
<td>Application type</td>
<td>On-Off application (UDP)</td>
</tr>
<tr>
<td>Downlink flow on time</td>
<td>100%, 80%, 60%, 40%</td>
</tr>
<tr>
<td>Uplink flow on time</td>
<td>100%</td>
</tr>
<tr>
<td>Packet size</td>
<td>1024 byte</td>
</tr>
<tr>
<td>LD input RF power</td>
<td>17.0206 dBm</td>
</tr>
<tr>
<td>RF active</td>
<td>5 channels (Best and Worst cases)</td>
</tr>
<tr>
<td>RF bandwidth</td>
<td>20 MHz</td>
</tr>
<tr>
<td>Propagation Loss Model</td>
<td>LogDistancePropagationLossModel [9]</td>
</tr>
<tr>
<td>Coupling loss (between downlink and uplink antennas in BS)</td>
<td>0 dB</td>
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</tbody>
</table>
The experiment measures the total uplink throughput when each frequency is shared by five mobile stations. Mobile stations and server are simultaneously sending data in both direction downlink and uplink.

Fig. 10 shows the uplink throughput in best and worst cases. Coupled downlink interfere uplink signal when the distance between BS and mobile station is more than 95 metre. The intermodulation distortion is alleviated when the downlink flow on time is decreased, because the IMD interference from coupled downlink is also decreased.

Fig. 11 shows uplink throughput performance at 115 metre. The best frequencies, which is the lowest intermodulation products, is the best performance and also in case of considering terminal mobility. However, total uplink throughput becomes low when downlink sending 100% of the data. While 40% of downlink data make better performance.

Fig. 12 shows the packet loss rate in uplink, when downlink sending 100% of the data, the highest packet loss was observed. You can see the same trend in the worst case.

VIII. CONCLUSIONS

In this paper, the intermodulation distortion between radio up/down link in multi-channel RoF has been addressed. From the result, coupled downlink signal interferes with uplink signal when distance between base station and mobile is more than 95 metre. Proposed method can reduce the interference by assign the optimum combination to the base station. Throughput performance is improved by the proposed method.
REFERENCES


